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PLATE I

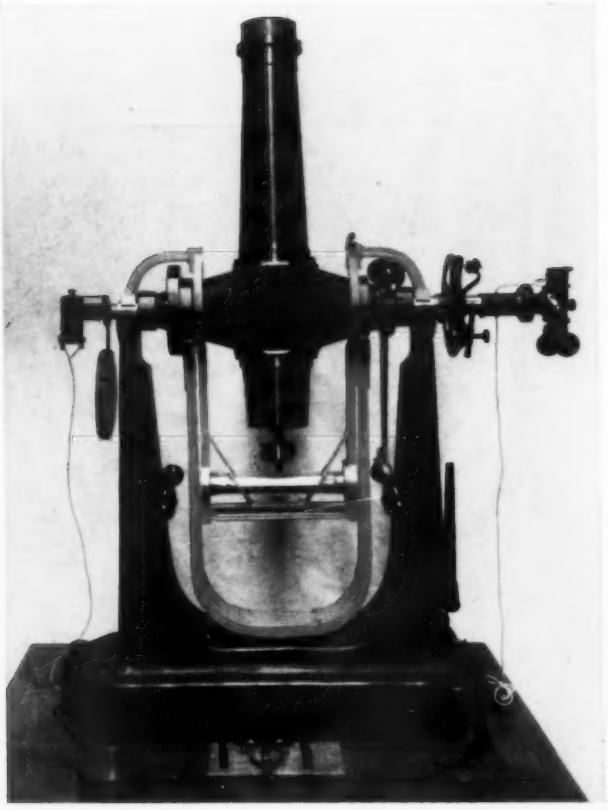

FIG. 1.—The broken-type Cooke transit telescope.

The objective lens is 3 inches in diameter. Light entering the telescope is bent at right-angles by a prism and directed along the hollow axis to an eyepiece. Fastened upon an extension of the other pivot is the light which illuminates the spider wires in the field of the eyepiece.

PLATE II

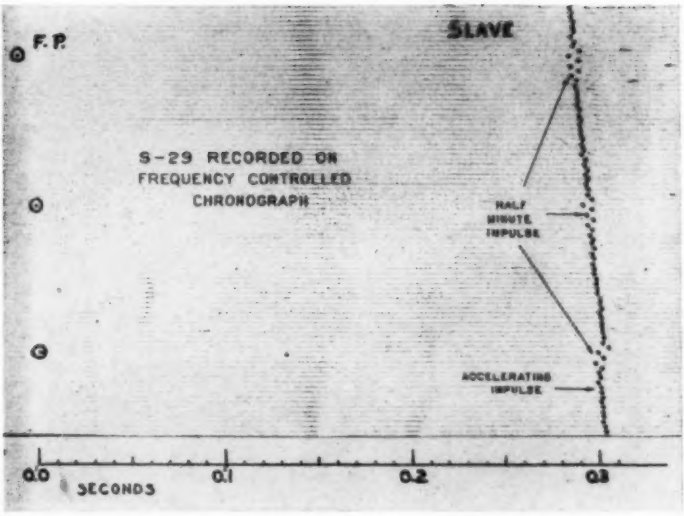

FIG. 3.—Record of clock beats on a chronograph.

S-29 clock beats, are recorded on a high-speed synchronous chronograph rotating at the rate of one revolution per second. The successive seconds show excellent continuity except following the maintaining impulse which occurs once every 30 seconds and the accelerating impulse which occurs, on the average, once per minute.

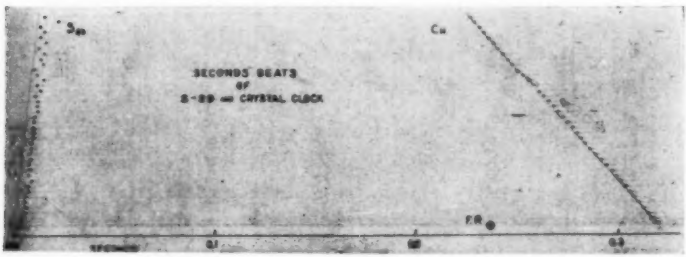

FIG. 4.—The synchronous chronograph.

Operating at two revolutions per second it shows definite irregularities in successive seconds of S-29 pendulum, while the seconds-beats of a crystal time-keeper CM prove to be very regular.

FIG. 5.—The time signal machine.

The half-seconds pendulum above is controlled by the primary astronomical clock of the Dominion Observatory. In turn it controls the rate of the time signal machine. There is a weight drive at the left, then, in turn, the day shaft, the hour shaft, a 5-minute shaft, two 1-minute shafts, with hour, minute and seconds dials on extensions of these shafts. Discs on the shafts are notched, and fingers which ride on the discs provide the various signals.

The shafts and gearing at the right are used to compare mechanically the half-seconds pendulum with the primary S-29, and to introduce the exact amount of advance or retard to the half-seconds pendulum.

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CANADA'S TIME SERVICE*

By M. M. THOMSON

(With Plates I-III)

ABSTRACT

Time signals which emanate by direct wire and by radio from the Dominion Observatory, Ottawa, now are available to the Canadian public from Halifax to Victoria, and northward to the limits of radio reception. An analysis is given of the accuracy of the time observations and of the time signals as distributed from the Dominion Observatory in Ottawa. Comparisons with other observatories are presented, and reference is made to the possibility, of improving the accuracy of the time service with the use of a photographic zenith tube and crystal-controlled time-keepers.

The important instruments associated with the Dominion Observatory Time Service are as follows:

1. The broken-type Cooke transit telescope.
2. The precise pendulum, Shortt No. 29 (S-29), and other precision time-keepers.
3. The Time-Signal-Machine for distributing the time.

THE BROKEN-TYPE COOKE TRANSIT TELESCOPE

The earth turning upon its axis provides the most convenient fundamental unit of time, and the distant stars are the best markers

*Vol. 2, No. 2, Contributions from the Dominion Observatory. Published by permission of the Director, Mines, Forests, and Scientific Services Branch, Department of Mines and Resources.

with which to measure this unit. A simple well-mounted telescope which can be trained onto the stars as they cross the meridian is essential to observe the period of rotation, and a time-keeper is needed to interpolate the time between clear nights. The early type of transit telescope had a series of fixed wires in the field of view, and as the star crossed each of the wires, the observer pressed a key. An accuracy of a few tenths of a second was thus obtained, but the personalities of the various observers resulted in large individual differences. A refinement came when the fixed wires were replaced by a pair of movable wires which could be moved across the field of view, keeping the star at the mid-point between the wires. Electrical contacts to record automatically the passage of the star are made as a secondary wheel moves with the driving wheels. A further refinement has been introduced by replacing the eye with a photographic plate in an instrument called a photographic zenith tube, reference to which will be made later.

The broken-type Cooke[1], which is in use at the Dominion Observatory (see figure 1) is a small telescope with a 3-inch objective, and a focal length of three feet. The cone of light which normally travels down the length of the telescope to an eyepiece at the end, is reflected in this instrument by a right-angle prism in the cube, or centre section, of the telescope and brought to a focus at one end of the axis of rotation. The eyepiece and micrometer cross-wires are mounted on an extension of one of the telescope pivots. Illumination for the field is provided by a rheostat-controlled light on an extension of the other pivot and introduced to the graticule of spider wires through a small hole in the prism. The movable wires of the impersonal hand-driven micrometer which are used to follow the star in transit are spaced about 1/500th of an inch. This space represents 0.72 second of time for an equatorial star, or about 1.0 second for a more slowly moving zenith star at the latitude of Ottawa. The electrical impulses which come from the telescope as the micrometer wires are made to follow the star are recorded on a chronograph along with clock-beats from the master clock.

Time transits at Ottawa were originally made with the larger 6-inch Meridian Circle telescope, but since 1935 the broken-type Cooke has been used exclusively. There are several advantages

[1]C. C. Smith, *Journal R.A.S.C.*, vol. 28, no. 8, 1934.

in the smaller instrument. Collimation errors are eliminated by reversing the small telescope on its pivots at the mid-point of each transit. The star is observed for a short period as it approaches the meridian, the instrument reversed, and the star is again observed for an equal and corresponding period after it leaves the meridian. The contacts recorded in the first half of the transit are gone over in reverse in the second half, so that the two series of contacts are mirror images of each other. The time of meridian passage of the star is determined by averaging the time of corresponding contacts, the first and the last, the second and second last, etc. Level readings in the case of the broken-type Cooke may be taken by means of the striding level before and after each transit and a level correction allowed for each star. With the eyepiece on the extension of one of the pivots, the observer has the same position for all stars regardless of declination, merely moving from one end of the pier to the other as the instrument is reversed. Time spent in reading the constants of the larger Meridian Circle can be spent in observing, and many nights that would be discarded for Meridian Circle purposes provided the hour or two required for a time set on the small transit instrument. The azimuth error, which is the amount by which the line through the pivots differs from the true east-west line, is determined by observing north polar stars. No azimuth correction has to be applied to a star which transits exactly in the zenith, and the correction is small for stars nearby. Hence the practice is to observe as near to the zenith as possible, balancing the observations fairly evenly to the north and the south.

Observations are made every clear night, the total number of star sets for 1946 being 209 on a total of 202 nights. The duty is not unpleasant during warm summer evenings, but in the cold of winter one has to guard against the cold and frost. Last winter (1946-47) personal comfort was improved greatly with the use of heated flying suits. Frost from the breath which tends to clog moving parts of the micrometer is prevented by wiping the parts frequently with alcohol.

Each star which is observed during the course of a night's work may be used separately to determine the error, or ΔT, of the master clock. The ΔT's from the several stars on any one night should be in close agreement since they are all measures of the same thing,

the error of the clock. When using the broken-type Cooke transit, an evening's work is considered good when the internal agreement is within 0.1 second. Occasionally the stars transited will agree within 0.07 second. During 1946 the average of all the nights was 0.14 second. At Greenwich, and other National Observatories where similar equipment is in use, similar results are obtained.

The observed correction, or ΔT, for each night is the result of careful work on the part of the observer and the computer. Even so, the ΔT's obtained on successive clear nights indicate rate changes in the primary clock which are far greater than are indicated by other clocks and by wireless signals. This is considered to be due to certain unavoidable errors in the astronomical observations. In other words, a good clock maintains a rate better than that indicated by visual star observations. The star observations have to be accumulated over a considerable period of time in order to determine the true progress of the primary clock. This is best

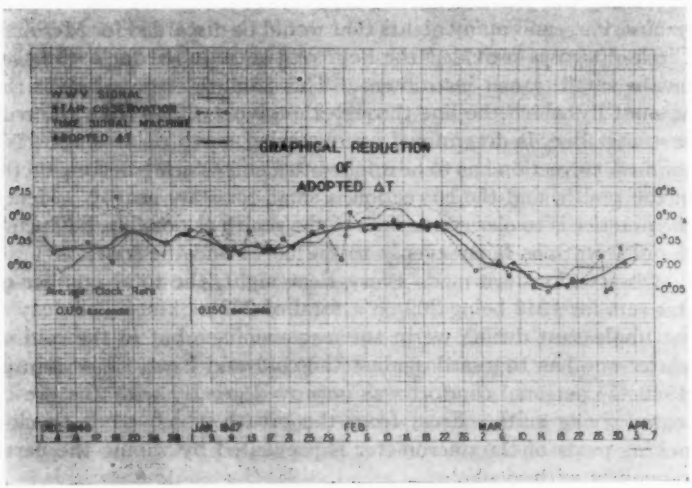


FIG. 2.—Graphical reduction of clock corrections.

The open circles represent actual star observations of time. A constant rate for the clock is extracted to keep the graph close to horizontal. The heavy line is the free-hand curve through the mean position of the star observations and represents the best known behaviour of the master clock. The deviation of the graph from the horizontal represents the deviation of the clock from a uniform rate. The change in rate of the master clock over long periods is small and gradual.

done by plotting the star results on graph paper (see figure 2). Then a smooth curve drawn through the mean position of these plotted points will indicate the most likely course of the primary clock. On the same chart are plotted the wireless signals from other observatories which, together with secondary reference clocks at the Observatory, help in determining the behaviour of the master clock during periods of cloudy weather. The day-to-day values which may be read from the smooth curve are called the adopted corrections, or adopted ΔT's, of the master clock. The average of the scattering of the observed values from the smooth curve affords a means of comparing the results of one observatory with another. It is found from the publications of both Bordeaux France and Rugby England that a similar scattering of observed from smoothed values exists as at Ottawa. It would appear that little improvement is to be expected with the instruments at present in use at Ottawa for the determination of clock error by star transits. The visual method of observing is the weakest link in the chain of precise time-keeping.

In connection with the type of errors mentioned above, a very great increase in accuracy has been effected by the substitution of photographic for visual methods of observing. The instrument by means of which this is done is called a photographic zenith tube and consists of a fixed vertical telescope so arranged that the cone of light from the objective is reflected from the surface of a mercury bath before coming to a focus on a small photographic plate below the lens. Considerable experience has been accumulated in the use of this instrument at Washington, on the basis of which the International Astronomical Union has recommended it to other observatories. One is being constructed for use at Greenwich. An improved design based on the one already in use at Washington is being constructed by the U.S. Naval Observatory for use in Cuba, which is much closer to the equator. It is hoped that observing equipment of this kind may eventually be made available at Ottawa.

The Primary Time-Keeper Shortt No. 29 (S-29)

The primary time-keeper at Ottawa is a Shortt pendulum No. 29, called S-29.[2] This time-keeper exhibits all the excellent

[2]F. Hope-Jones, *Journal of Royal Society of Arts* No. 3731, vol. 72, 1924

qualities of its make as well as the inherent weaknesses. It will run free from stoppages for years at a time, and suffers only small long-term changes in rate. The Shortt clock consists of two pendulums, one free, the other a slave. The free pendulum is carefully housed in its vacuum chamber in a temperature-controlled vault. The slave pendulum, looking much like a grandfather clock, is on the wall of the Time Room. Each half-minute the slave pendulum releases a gravity arm which applies an impulse sufficient to keep itself going for another half-minute. The same action releases electrically a similar gravity arm within the case of the free pendulum. The slave is rated to lose 0.004 second a minute on the free. Alternate half-minutes, an accelerating impulse of 0.004 second is imparted to the slave by the same electrical circuit which causes the gravity arm of the free pendulum to return to its "up" position. Thus the lave is held in synchronism with the free.

Both the maintaining impulse which occurs each half-minute and the accelerating impulse which occurs alternate half-minutes cause short-period fluctuations in the slave pendulum. The 8 or 10 seconds following the half-minute are alternately long and short (see figure 3), and the difference at times being as much as 0.007 second. The average time remains undisturbed. The accelerating impulse causes an advance in the time of the slave by 0.004 second. These two effects are shown when the clock-beats of S-29 are recorded on a high-speed synchronous chronograph. The recordings of figures 3 and 4 were made with the drum rotating at one revolution per second, the frequency control being a 50-cycle tuning fork.

Advantages of Crystal Clocks

Many of the disadvantages of a pendulum time-keeper are overcome by a type of clock which makes use of the regularity of vibrations of a quartz crystal for the purpose of controlling its rate. Successive seconds of a quartz-crystal time-keeper prove to have much greater regularity than S-29, as is illustrated in figure 4.

It is not easy to compare mean time seconds directly with sidereal because of the greater length of the mean time intervals. The ratio of the length of mean time seconds to sidereal time seconds is $365\frac{1}{4}$ to $366\frac{1}{4}$. The result is that successive mean time

seconds come later and later relative to the sidereal seconds and the mean time seconds in figure 4 slope off to the right.

To-day the trend at major observatories is to adopt the crystal clock for precise time-keeping. The crystal unit subdivides time accurately into very small parts of a second, is capable of controlling rotating mechanisms for all manner of time distribution, and is capable, by a simple gear reduction, of delivering sidereal time and hence serving as an astronomical observing clock.

There has been a General Radio crystal clock at the Dominion Observatory since April, 1942. The first crystal unit had too high an acceleration. In 1944 an exchange was made, and the acceleration in the present crystal has steadily declined. Its present acceleration is less than 0.001 second per day per day. And it is sufficiently steady that it provides an excellent companion for the primary S-29. Ultimately it is hoped to secure additional crystal clocks for the time-service. No clock of itself is sufficiently reliable for its rate to be projected for several days between star observations. Additional clocks are required with the same degree of precision to serve as comparison time-keepers. Then, too, crystal time-keepers are subject to stoppages, a fault which current research will no doubt overcome. A six-month run for the Observatory clock is somewhat of a record.

The need for additional crystal clocks has been eased, though not lifted, by co-operation among government departments. The Radio Monitoring Station of the Department of Transport has a frequency standard involving three quartz-crystal units. A 1,000-cycle per second output from this is supplied to the Dominion Observatory and is used to operate a 1,000-cycle clock. Similarly a 60-cycle output from a crystal frequency standard at the National Research Council is used to operate a clock at the Observatory. The arrangement is a happy one but with definite limitations. Failure in the connecting lines, and rate changes introduced by the personnel operating the standards, both serve to shorten the periods during which their rates may be used at the Observatory. It is hoped eventually to increase the number of crystal time-keepers at the Dominion Observatory where their control may be observed by time-service personnel. At both Greenwich England and Washington U.S.A. the older pendulum clocks have been

superseded by the newer quartz-crystal clocks. Both the precision and the regularity of time signals provided by these two institutions has been thereby greatly improved.

The Time-Signal-Machine

The Time-Signal-Machine (figure 5) is a set of discs on shafts which are geared together and driven by a weight. The discs are notched at regular intervals and fingers which feel the discs much like a music box provide the various impulses on the second, the minute or the hour. A short half-seconds pendulum which swings twice as fast as a standard seconds pendulum provides the control for the signal machine. The pendulum is rated to mean time, but is cleverly held to true time by the primary S-29 which is rated to sidereal time. The ratio between the two times, mean and sidereal, is 365.2422 to 366.2422, which means that each time the mean time pendulum completes 365.2422 seconds, it should for an instant be in exact coincidence with the sidereal pendulum. If the coincidence occurs late, it would indicate that the mean time pendulum is swinging fast relative to S-29, and a suitable correction is applied. If the coincidence comes too early, the mean time pendulum is swinging too slow, and a suitable accelerating impulse is applied. This duty is performed quite automatically by the time-signal-machine every 365.2422 seconds or approximately 10 times an hour. The correcting impulse which accelerates or slows up the control pendulum amounts to 0.0007 second per second, which means that the length of the seconds delivered by the time-signal-machine differs from the length of a true mean time second by less than a thousandth of a second even during the period that a correction is being applied. And after the correction period, the half-seconds pendulum is in step with the best known value of true time that the primary pendulum is capable of supplying.

There are two identical units of the time-signal-machine, each with its own control pendulum, so that when one is closed down for repairs the other will carry on. Otherwise one is running idle in readiness for any emergency. The time-signal-machines were designed by the former Dominion Astronomer, Mr. R. M. Stewart,

constructed in the Observatory machine shop, and set in operation in 1938.

Defects of this system are due to the following considerations:

1. The daily rate of S-29, which is a little more than a tenth of a second a day losing, has to be accounted for mechanically by the time-signal-machine. The mechanism for doing this can be set only to the nearest hundredth of a second. Frequent adjustments have to be made in order to keep the clock correction indicated by the time-signal-machine the same as the correction indicated by star observations.

2. The moment of coincidence between the half-seconds pendulum and S-29 may occur during a period when the slave seconds are irregular following the half-minute maintaining impulse. Or it may occur while the 0.004 second accelerating impulse is being administered to the slave. These two defects combined may mean that the time of the half-seconds pendulum before and after a correction may differ by as much as 0.01 second.

3. The half-seconds pendulum may, itself, have a variable rate because its protective case is merely dust proof and does not provide temperature or pressure control. The pendulum is compensated for temperature only.

4. The time-signal-machine operates with an escapement, and the resulting banging, starting and stopping, is not now considered to be good for the mechanism or for the personnel who are obliged to work in the same room. A proposed improvement is to have the time-signal-machine operated by a controlled-frequency motor, the primary control being a crystal clock. It is readily adaptable to the greater precision of a crystal control.

The above mentioned defects should not be over emphasized. A pendulum time-keeper has the advantage of long uninterrupted service, a distinction towards which the crystal time-keeper is progressing. It is perhaps worth repeating that in the present system of time-keeping at the Dominion Observatory, the actual star observations constitute the weakest link.

The accuracy of the time-signal-machine is only slightly less than that of S-29. And since the variations in the seconds-beats of S-29 from hour to hour are normally less than 0.01 second, the

short-period fluctuations in the time-signal-machine seldom exceed 0.01 second. From day to day the rate of S-29 holds closely to a steady value. Between January 1 and April 30, 1947, the rate of S-29 varied slowly between 0.13 second and 0.16 second per day (see figure 2). But the over-all rate was about 0.148 second. The short-period fluctuations of 0.01 second or less are of too small an order to be detected by surveyors and other government or private field parties, though the errors will be incorporated in their results. Nor are they of concern to the average Canadian who hears the C.B.C. signal at one o'clock eastern time each day. They are, however, too large for present day laboratory measurements unless the measurements can be made over an extended period of time.

The Broadcast of Time-Signals

By Order in Council P.C. 6784, Aug. 28, 1941, the Dominion Observatory time was declared the time to be used for official purposes in Canada. For many years previous to this the Observatory had unofficially served as a source of accurate time for a variety of purposes. The present Dominion Observatory, built in 1903 and 1904, was an outgrowth from a small government observatory in Ottawa. One purpose was to provide a base for the survey of Canada, which meant a program of star observations and the maintaining of correct time. Transmission of time impulses from the Dominion Observatory to the local telegraph offices was commenced in January, 1905, and was used to co-ordinate field work by direct telegraph communication, prior to the time that radio time-signals came into common use. Wireless transmission was first made over the local broadcasting station C.N.R. in 1923. In that same year sidereal time impulses were broadcast directly from the Dominion Observatory to a nearby field seismological station to co-ordinate the field results with those obtained at the Observatory. Direct radio broadcasting of mean time from the Observatory commenced experimentally in 1927, using the short-wave bands of 20.4 metres, 40.8 metres, and 90 metres. These later became the more exact frequencies defined below. The early program included a daily 15 to 20 minute transmission on 40.8 metres at 10.00 p.m. A low-power signal on 90 metres was maintained as continuous as battery supply would allow. By 1933, the use of

rectifiers made the continuous operation of transmitters more practical, eliminating both rotating converters and banks of Edison cells. Since then the 3330 kc. and 7335 kc. frequencies have had but minor interruptions and gradually increasing power. Now all three frequencies are operating under the call sign CHU and a power output of about 300 watts.

The arrangement by means of which radio time-signals are now broadcast from the Dominion Observatory is an interesting commentary on inter-departmental co-operation. The three transmitters in use are each of type AT3, designed by R.C.A. during the war for use in the R.C.A.F., and on request were made available on indefinite loan from the R.C.A.F. to the Observatory as surplus equipment in the spring of 1947. This was mutually advantageous. The Department of National Defence is desirous of obtaining time signals in connection with research projects, and the time-service is pleased to have a 6-fold increase in signal strength. The problem of housing the transmitters was cared for by the Radio Branch of the Department of Transport. Close co-operation between the time-service and the Radio Branch has been maintained for a number of years. From their quartz-crystal frequency standard a 1,000-cycle frequency is delivered to the Observatory and controls a clock which is used to assist in precise time-keeping. Also one of their transmitters (VAA) has been used since July, 1938, for a 5-minute period of time transmission daily. Since 1942, continuous all-night transmissions of time signals have been made available for the benefit of scientific field parties during the summer months. This latter service was discontinued this year since the new CHU transmitters were installed by June.

A summary of signals controlled by the time-signal-machine is as follows:

(*a*) *The Noon C.B.C. Broadcast.* At present the C.B.C. network of over 50 broadcast stations transmits time signals at 1300 hours eastern time. Eastern time refers to standard or daylight saving, whichever prevails at Ottawa. Second beats with a musical pitch of 800-cycles per second commence about 12 hr. 59 min. 20 sec. and carry through to the hour, omitting the 29th and also the 51st to 59th seconds. A gap of 9 seconds always precedes the long dash on the hour.

(*b*) *Continuous Short-Wave Signals.* The three Observatory transmitters are on the air continuously 24 hours a day with the call sign CHU transmitting second-beats on frequencies of 3330 kc., 7335 kc. and 14760 kc. for the benefit of surveyors, navigators, scientific institutions and others who require this type of service. The musical pitch of 1,000-cycles per second, which is characteristic of these signals, is derived from a precise crystal source.

(*c*) *Other Radio Transmissions.* Short-period transmissions of second-beats for the benefit of mariners and for people at northern outposts are sent daily from the following stations which have direct wire connection with the Observatory.

CFH Halifax	111 kc. 0955-1000 hrs. and 2155-2200 hrs. EST
VAA Ottawa	11990 kc. 1055-1100 hrs. EST
VAP Churchill	500 kc. 1058-1100 hrs. EST (using C.N. coded signals)

The C.N. and C.P. telegraph companies receive specially coded time-signals to serve their separate requirements, the C.N. from 1058 to 1100 hrs. EST, and the C.P. from 1154 to 1156 hrs. EST daily.

(*d*) *Additional services* of a local nature include the control of some 800 minute-dials in 14 government buildings, the identification beat for seismograph records, and also special relay circuits for special purposes.

The method employed by the U.S. Naval Observatory for identifying continuous signals was adopted by the Dominion Observatory in 1934. At first a tape was used to provide the omissions at the right time. But since 1938 this has been done by the time-signal-machine. Identification is accomplished by a series of omissions at the end of each minute, the series repeating itself each five minutes as follows:

1st minute—29, 51, 56 - 59
2nd minute—29, 52, 56 - 59
3rd minute—29, 53, 56 - 59
4th minute—29, 54, 56 - 59
5th minute—29, 51 - 59

Alternatively this may be shown as follows, remembering that the 29th second is omitted from every minute.

Seconds	50	51	52	53	54	55	56	57	58	59	60
1st minute	–		–	–	–	–					–
2nd minute	–	–		–	–	–					–
3rd minute	–	–	–		–	–					–
4th minute	–	–	–	–		–					–
5th minute	–										–

Hence, when the 51st second is omitted and 4 more beats are sent, it indicates that there will be 4 more minutes to a 5-minute interval. At the end of the 2nd minute, 52 is omitted and 3 more beats are sent, indicating that there are 3 more minutes to the 5-minute interval, etc. The end of the 5th minute has the long gap from the 51st to 59th beats. During the first minute of each hour, the call sign C-H-U is sent slowly in morse code twice. The 2nd and subsequent minutes of the hour correspond to the 2nd and subsequent minutes of a 5-minute group.

If a time-piece is in error by not more than a minute or two it is possible to identify the radio signal immediately and to adjust the time-piece precisely. In the case of a larger error, it may be necessary to wait for the hour identification. The beginning of each second beat marks the exact time.

Ottawa Compared with other Observatories

For years prior to the war, radio time-signals were received daily from Rugby England, Bordeaux France, Nauen Germany, Washington U.S.A., Monte Grande Argentine, and Rio de Janeiro Brazil. The results were submitted to the Bureau International de l'Heure, France, and were used to compare the effective results of Ottawa time-determinations with those of fifteen other observatories. The scale of the chart in figure 6 which shows the results for 1938 is 0.02 second per division vertically, and five days per division horizontally. It will be noted that the Ottawa record has short-period variations which may, in part, be due to following the star observations more closely than the rate of the clock would warrant.

Since the war, the program of signal-reception has been restricted to those sent from the Washington Naval Observatory (NSS), and from the U.S. Bureau of Standards (WWV). The equipment at the disposal of the Naval Observatory includes several

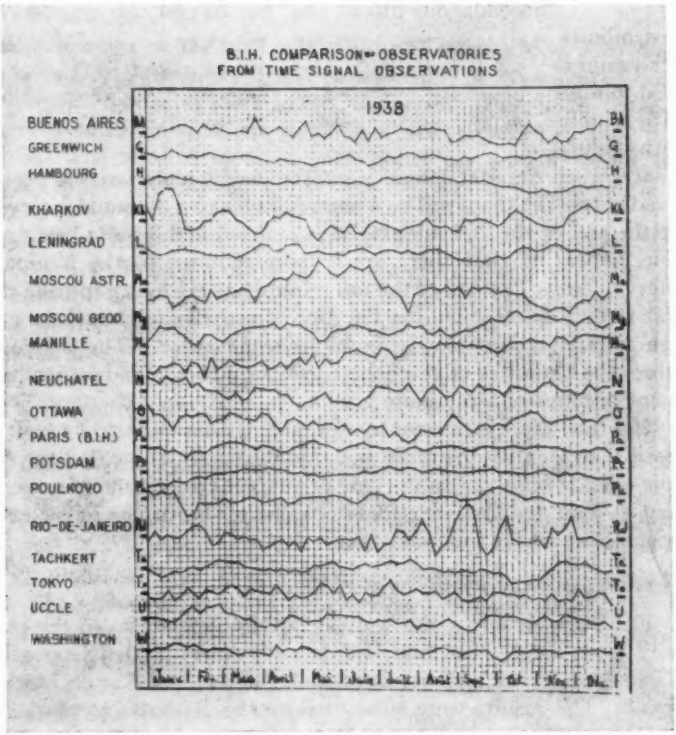


FIG. 6.—Comparison of results from fifteen observatories.

The results of 15 observatories have been averaged as the basis upon which to compare each of the observatories listed above. The scale of the chart is 5 days per division horizontally and 0.02 second per division vertically. The deviations from the horizontal represent a measure of the unavoidable errors of time determination.

crystal clocks and a photographic zenith tube. For some time comparisons between the Washington signals and the output of the time signal machine at Ottawa have been made, and it has been found that the day-to-day variations in the Ottawa signal are greater. A more interesting comparison is seen in the published corrections to the WWV time-signals published by both Ottawa

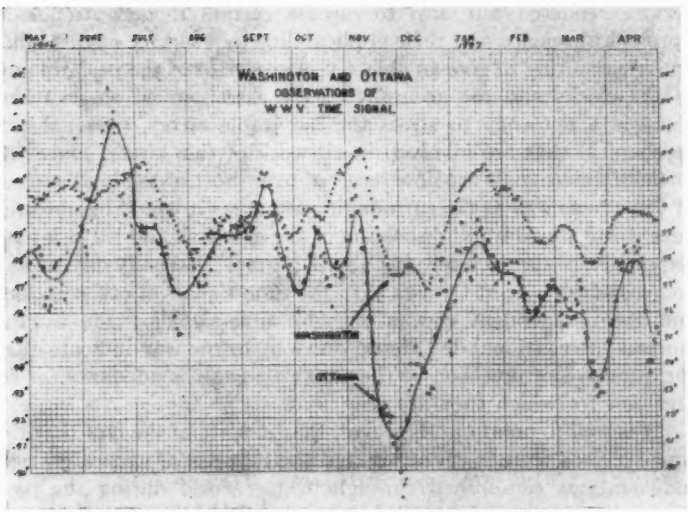


FIG. 7.—Comparison of determinations at Washington and Ottawa.

Time signals emitted by the U.S. National Bureau of Standards are received by both the U.S. Naval Observatory at Washington and by the Dominion Observatory at Ottawa. Each Observatory determines the exact time of signal-reception on the basis of star observations. The chart above may then be considered a direct comparison of the time determinations at Washington and Ottawa. In general the correlation is very good. However, the greater refinement possible with photographic methods of observation and crystal time-keepers at Washington result in a smaller scatter of points on the curve. There is some evidence of a systematic difference which is being made the subject of detailed investigation.

and Washington (figure 7). When plotted together, they show a high degree of correlation, indicating that the fundamental time as determined at the two observatories is always in agreement within a few hundredths of a second. But the greater refinements possible with the use of a photographic zenith tube and with a battery of crystal time-keepers as primary clocks seem to be demonstrated.

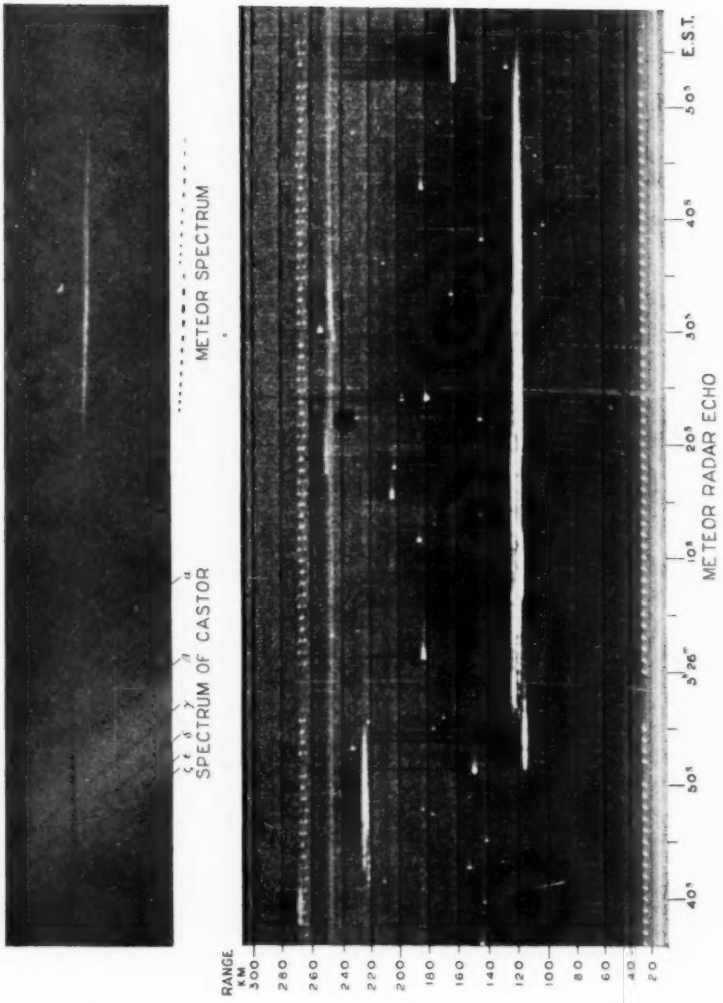
CONCLUSION

In the foregoing description of Canada's Time Service an attempt has been made not only to describe the instrumental equipment in use at the Dominion Observatory and the type of

service rendered but also to discuss certain modern trends in horological science and their applicability to a service of this kind. In endeavouring to give an objective assessment of the performance of the clocks and the accuracy of the astronomical observations there is a tendency to stress the inevitable errors, personal and mechanical that are involved in all work of this kind. Since the Ottawa time-signals are now received over most of the land surface of Canada as well as the surrounding sea areas it would be unfortunate if the above frank discussion of the errors should leave a false impression of the accuracy of Canadian time. Actually day-to-day comparisons made at Ottawa with the time-signals of other nations and the independent checks of radio time-signals made by the Bureau International de l'Heure previous to the war indicate that the standard of precision of the Ottawa signals is adequate for all purposes for which they are now used.

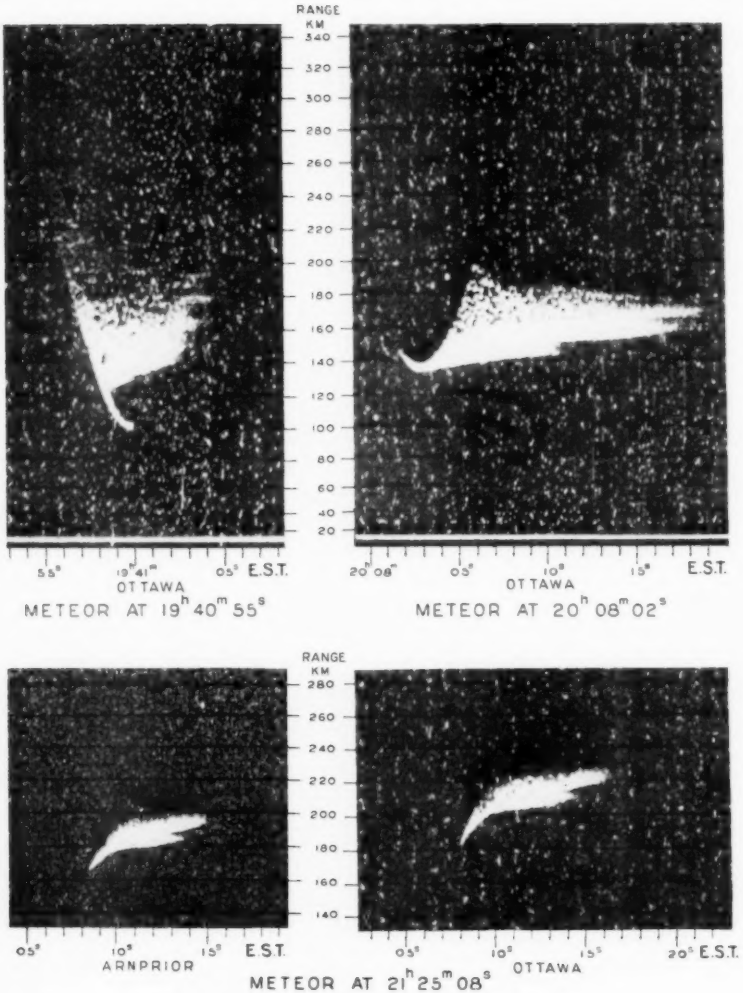
It is well to point out, however, that in spite of the fact that the time-services of most countries, and the network of accurate longitude stations established throughout the world during the past few decades, are dependent on the types of observations and instruments described here, there is no doubt that the more modern methods of photographic observation and crystal-clock time-keeping are likely eventually to result in increased accuracy. A start in the testing and use of these devices has already been made at Ottawa with the acquisition of a crystal clock, and careful consideration is being given to the matter of photographic methods of observation. Whether the newer methods will only supplement or entirely supersede those now in use is something that only experience can decide. It is possible that the extreme temperatures of the Canadian winter may interfere with the operation of a photographic zenith tube and that it may be necessary to retain the transit telescope in order to bridge over periods of severe cold when an instrument making use of reflection from a mercury bath cannot be used.

PLATE IV



Bright Geminid Meteor at $5^h\ 25^m\ 41^s$ E.S.T., December 13, 1947.

PLATE V



Radar echoes of three Lyrid Meteors, April 21, 1948.

A NOTE ON FOUR COMPLEX METEOR RADAR ECHOES

By PETER M. MILLMAN* and D. W. R. MCKINLEY†

(With Plates IV and V)

ABSTRACT

The radar echoes of four bright meteors, one Geminid and three Lyrids, are studied in detail. All four echoes have an enduring portion of complex character, centered at a height of 90 km., and at least three have an instantaneous component which seems to move with the velocity of the meteor itself. Measurements made on these echoes indicate velocities of 35 km./sec. for the Geminid shower and 48 km./sec. for the Lyrid shower.

DURING the year 1947 the Dominion Observatory and the National Research Council instituted a series of cooperative programs of meteor observation in Ottawa. These programs were organized particularly with a view to obtaining observational data on the correlation between the meteors as visually and photographically recorded, and the radar echoes which the meteors produce. Preliminary results of the observations of the Perseid meteor shower of 1947 have been published recently in *Nature*,[1] and it is hoped that a more complete account will appear in an early number of this JOURNAL. Successful programs were also carried out at the time of the Geminid shower in December 1947, and during the Lyrid and Aquarid showers in April and May 1948. A large amount of observational data has been collected including 45 meteor photographs, both direct and spectroscopic, 1850 visual meteor plots, and over 100,000 meteor radar echoes photographed on the cathode ray tube. There has been no opportunity as yet to complete an analysis of these numerous records, but it was thought that it might be of interest to describe here in some detail the observations of four meteors (one Geminid and three Lyrids) which produced radar echoes of particular significance.

The radar observations of these meteors were made using a frequency of 32.5 megacycles (wave-length 9.2 metres), the trans-

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mitter having a peak power in the neighbourhood of 300 kw. and the receiver a sensitivity of 2×10^{-14} watts. Both transmitting and receiving aerials were simple half-wave dipoles placed horizontally, the antenna pattern being omnidirectional. The radar equipment was designed and operated by the Radio and Electrical Engineering Division of N.R.C. Meteor spectrographs and direct cameras were operated by the Dominion Observatory, and members of the Observatory and N.R.C. staff, assisted by volunteers from the Ottawa Centre of the Royal Astronomical Society, made the visual observations. The Ottawa Station was located at the Metcalfe Road Field Station of N.R.C., a few miles south of Ottawa at lat. 45° 21′ N., long. 75° 38′ W. During the Lyrid and Aquarid observations a second station, with radar equipment of considerably lower power, was also operated on some nights. This was located at the Flight Research Section, N.R.C., Arnprior Airport, at lat. 45° 25′ N., long. 76° 22′ W., with a true bearing 278° and distance 57km. from the Ottawa Station.

The brightest meteor observed during the three nights of the Geminid program was a Geminid meteor of visual magnitude -3 which appeared close to the radiant and was visually recorded at $5^h\ 25^m\ 41^s$ E.S.T. on the morning of Dec. 13, 1947. This meteor left a persistent train which remained visible for 9 seconds. Unfortunately the direct camera covering the field was temporarily closed, but the meteor was photographed on a meteor spectrograph (Camera U with lens of focal length 150 mm. and a 30° flint prism). The plate used was Eastman Spectroscopic 103aF, which is a panchromatic plate with a fairly uniform sensitivity to a wavelength of about 6800 angstroms. The camera lens was covered by a rotating shutter ten times per second, the period of occultation being twice the exposure. The meteor spectrum obtained, reproduced in Plate IV, is poor owing to the fact that the motion of the meteor was almost along the dispersion so that it is difficult to identify the details of the spectrum. Two strong lines, or blends, are visible, one in the violet and the other in the green. At least twelve separate segments of the violet line are present and three more at the end of the trail are doubtful. The meteor was, therefore, photographed over a path length corresponding to the motion of the meteor for at least 1.2 sec. and possibly for as long as 1.5 sec.

Preliminary measures of the spectrum leave some doubt as to the correct identification of details in it but from analogy with other spectra secured on the same program it seems highly probable that the strong violet line is the magnesium multiplet at 3835 angstroms and the other line is the magnesium green triplet at 5175 angstroms.

The complex radar echo of this meteor is also reproduced in Plate IV. The radar presentation shows the range, or distance from the observer, plotted against standard time, indicated by the time markers received from radio station CHU at top and bottom of the record. In effective coincidence with the visual appearance of the meteor at 41 seconds a sharp echo was recorded extending from a range of 113.5 km. to 89 km. over a time interval of 0.70 seconds. This echo is a straight line and increases gradually in strength over most of its length, its motion apparently corresponding to that of the meteor itself. This type of echo was first observed by Hay, Parsons and Stewart during the Giacobinid Shower of 1946.[2] Following this instantaneous echo after an interval of about 10 seconds, a complex enduring echo appeared at somewhat greater ranges. Details of the three chief components of this echo are listed below, the delay times being measured from the extension of the first echo projected back to greater ranges, and durations representing the periods over which the components were visible.

Component	*Range*	*Delay*	*Duration*
e_1	121 km.	14.8 sec.	60 sec.
e_2	119	15.0	
e_3	115	10.4	8

The picture is confused by the appearance of a range marker between e_1 and e_2 and a general tendency of all components to merge toward the last. What may be a fourth component, or merely a reappearance of e_3, is seen starting at $26^m\ 06^s$, 25 seconds after the visual meteor.

By combining the information from the meteor photograph and the radar echo it is possible to determine completely the elements of the path of this meteor through the atmosphere. Assuming that the meteor was near the radiant a preliminary velocity was computed from the slope of the instantaneous (or head) echo. This was very close to 35 km./sec., which agrees with Whipple's determination of Geminid velocities.[3] Now, by assuming this velocity,

and using the radar range combined with measures of the segments in the meteor spectrum, the position of the apparent radiant for this meteor was computed graphically as at R.A. 113°.0, Dec. + 33°.1. The mean position of the apparent Geminid Radiant at Ottawa for this time, taken from Whipple,[3] is R.A. 113°.4, Dec. + 33°.1, showing good agreement. Given the above position of the radiant, the following values for the other elements of the meteor's path were computed. The heights for the photographed path were determined approximately by assuming the sudden drop in luminosity near the end of the path to correspond to the end of the radar head echo.

Apparent radiant——elevation 50°.7, true bearing 269°.4		
Photographed path—	height beginning	100 km.
	" end	60 km.
	path length	52 km.
	elongation from radiant (α)	2°.7 − 4°.4
Radar head echo (h)—	height beginning	87.5 km.
	" end	68.5 km.
	geocentric velocity	35.1 km./sec.
Radar enduring echoes (e)—height	e_1	93.5 km.
	" e_2	92.0 km.
	" e_3	88.5 km.
Total radar path length		32 km.
Magnitude (if observed in zenith, distance 100 km.)		− 3

The accuracy of the absolute values read from the radar record is of the order of one per cent, but relative heights can probably be relied on to half a kilometre. In general we have found that the great majority of radar meteor echoes occur at heights greater than 80 km., and the long-enduring type are situated within a layer 15 to 20 km. thick centered somewhere between 90 and 100 km. above sea level. It is evident from this example, however, that in the case of a very bright meteor the instantaneous head echo may appear considerably lower than 80 km.

It is tempting to speculate upon the possible connection with this same meteor of the echoes at ranges of 222 km. and 268 km., but a considerable amount of statistical work will have to be done before anything definite can be said in this regard. If these higher echoes were produced by the same meteor they would have heights of 174 km. and 219 km., and delays in appearance of 2.9 sec. and 0.6 sec., respectively. An as alternative speculation one might

consider that the echo at 222 km. was a multiple cloud-to-ground reflection, similar to the multiple ionospheric reflections obtained with vertical incidence equipment. The total range in this case would be the range to the ionized cloud formed by the meteor plus a distance at least equal to the height of the cloud but possibly greater, depending on the point of ground reflection. The rough similarity of the echo at 222 km. to the main echoes also suggests this interpretation.

The three Lyrid echoes appeared within a period of two hours early in the evening of April 21 and may conveniently be considered together. Radar records of the first two were obtained at the Ottawa Station only, as the equipment at Arnprior was temporarily out of operation. The third echo was observed at both Ottawa and Arnprior, however, and the radar observations of the three meteors are reproduced in Plate V. Unfortunately, visual observations had not commenced when the first two meteors occurred and only the third was visually recorded at Ottawa, a 1st magnitude Lyrid in the constellation Monoceros. Reducing to a standard luminosity, i.e., the magnitude the meteor would have if observed in the zenith at a distance of 100 km., gives us a zenith magnitude -1.

It should be pointed out that the lack of visual observations for the first two meteors, and the large angular distance of the third from the Lyrid radiant, might seem at first sight to cast doubt on the certain identification of these three meteors with the Lyrid shower. After a careful study of various possibilities, however, we believe that the internal evidence presented by the echoes themselves, when taken with the known position of the Lyrid radiant at the time, makes it very improbable that any of these meteors were non-Lyrids.

Assuming a mean position of the Lyrid radiant at R.A. 275°, and Dec. $+35°$, and applying to this the appropriate correction for the earth's gravity (zenith attraction), the apparent elevations and true bearings of the radiant were computed for the times of appearance of the three meteors.

	E.S.T.	*Radiant elevation*	*Radiant true bearing*
Lyrid meteor I.....	$19^h\ 41^m$	3°	038°
" " II.....	20 08	6	042
" " III.....	21 25	16	055

It will be seen that all three meteors appeared while the radiant was low in the sky and it is believed that it is this circumstance which is chiefly responsible for the remarkable appearance of the echoes. As noted above, most of the enduring meteor radar echoes seem to occur in a fairly restricted horizontal layer in the upper atmosphere, of the order of 15 to 20 km. thick. If a meteor moves through this layer almost horizontally, its path within the layer will be correspondingly longer, and the chances of producing a radar echo over an extended path length will be increased.

The range-time plot of a meteor moving past an observer along a straight line at a constant velocity will be in the form of a hyperbola. The two arms of this curve correspond to the approach and recession of the meteor respectively, and the form of the hyperbola will depend upon the meteor's velocity, and the length of the perpendicular from the observer to the meteor's path. The appearance of hyperbolic forms in the echoes from Meteors I and II indicates that, as in the case of the Geminid echo discussed earlier, we have here a radar echo moving with the velocity of the meteor. The Lyrids are associated with Comet 1861 I, which is moving in a near-parabolic orbit with a period of over 400 years and a geocentric velocity, when near the earth, of 48 km./sec. Olivier[4] gives a number of references to early determinations of the Lyrid orbit, giving geocentric velocities from 45 to 48 km./sec. Watson[5] gives 51 km./sec. as the Lyrid velocity, assuming a parabolic orbit. This may be regarded as the upper possible limit of Lyrid velocity. In Figure 1 the general outlines of the Lyrid meteor echoes have been traced in dotted lines and the theoretical hyperbolas corresponding to a velocity of 51 km./sec. have been superposed in each case as solid lines. The velocity indicated by Echoes I and II is 48 km./sec., slightly less than that for which the hyperbolas have been plotted. There was only one other Lyrid meteor on the night of April 21-22 for which a reasonably reliable velocity could be computed from the radar echo and the visual plot. This was a 2nd magnitude Lyrid within 6 degrees of the radiant and it had a head echo which gave a velocity of 50 ± 3 km./sec. The above radar velocities are in good agreement with an unpublished Harvard-M.I.T. velocity of 48.6 km./sec. for a Lyrid meteor photographed in 1941.

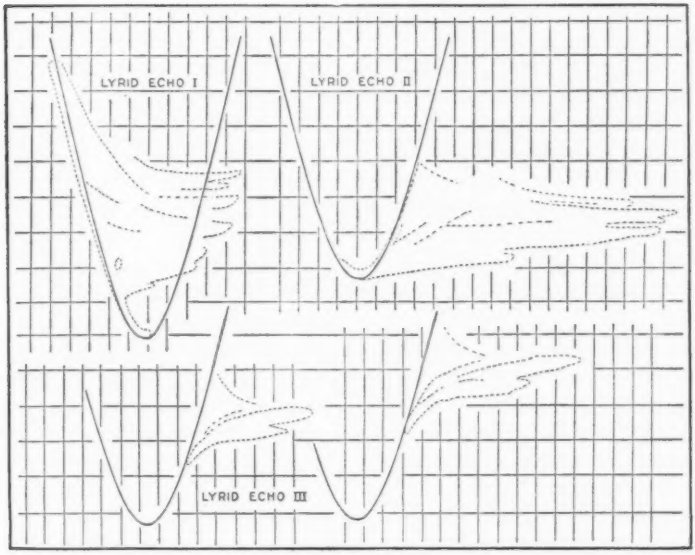

FIG. 1 Outlines of three Lyrid echoes plotted as dashed lines; basic hyperbolas for velocity of 51 km./sec., plotted as solid lines. Abscissae are standard times, indicated at one-second intervals; ordinates are ranges, indicated at 20 km. intervals.

Since the radar records give range only, and since the only visual observation available here is of Meteor III, which was moving almost perpendicular to the horizon, the height of the enduring portion of these meteor echoes is indeterminant without using additional information. The echoes of 15 meteors, observed on the same night both visually and with the radar, showed a marked concentration between heights of 80 and 100 km. with a mean at 90 km. It seems logical to assume a mean height of 90 km. for the enduring portion of the three Lyrid echoes. This assumption also satisfies the relative radar ranges of Meteor III as measured at Ottawa and Arnprior and agrees with the observed visual altitude of the meteor, but indicates that the visual plot was somewhat too far north in bearing, or azimuth. This is quite possible as the

meteor was observed over a flat roof before regular recording and plotting had commenced.

The elongation of Meteor III from the radiant is so great that the outline of the moving echo does not correspond to the head velocity but shows a progressive delay in appearance, a feature noted in a number of Perseid echoes.[1] Attempts to fit the echoes of Meteor III to a more open hyperbola have proved unsuccessful for various reasons. On the average it has been found that the delay in appearance of the enduring echoes is least for α (the elongation from the radiant) equal to 90°, and increases as α differs more widely from 90°. This delay must represent the average time necessary for the ionized cloud to assume proportions large enough to provide an adequate echoing surface and will be longer the more nearly end-on the meteor path is viewed. The only agency capable of producing instantaneously an ionized volume sufficient to produce the "*h*" characteristic, or head echo, would seem to be that of intense ultra-violet light from the meteor luminosity.

From an examination of Plate V it will be seen that the enduring Lyrid echoes show the same complex structure already noted for the Geminid echo, and found previously as a common feature of echoes from bright Perseid meteors.[1] We consider this characteristic to be a function of the physical conditions of the atmosphere rather than of the meteor itself, and to indicate some type of fine structure in the layer containing the enduring echoes. It is too early yet to define the exact nature of this structure but its effect is to produce successive areas or patches along the meteor path which, owing to a higher effective ionization, reflect radar waves more efficiently than the space between the patches. Four main components of the enduring echo have been read for Meteors I and II, and two for Meteor III, though these are not very clear-cut for the first meteor. Assuming a velocity of 48 km./sec. for all three meteors, and knowing the elevation of the apparent radiant, the total radar path length and spread in height can be computed, as well as the horizontal and vertical spacings between the patches producing the components of the enduring echoes. These are listed below:

	Elongation from radiant	*Total radar path*		*Enduring echoes*		
	(α)	*length*	*height spread*	*vertical spacing*	*horizontal spacing*	*height spread*
Meteor I.....	21°- 98°	260 km.	14 km.	1.1 km.	21 km.	4 km.
" II....	67 -137	195	20	2.3	22	8
" III...	131 -144	65	18	4.4	16	5

The above values have been read from the Ottawa records. The Arnprior observation of Meteor III, made with less powerful equipment, shows the echo starting about 0.3 second later and of shorter duration, though the meteor was closer to Arnprior.

An examination of the echo forms reveals additional features of shorter duration than the enduring portions described above. A full discussion of the various echo forms that may be produced, and the reasons for their appearance, is not possible here. A longer theoretical paper has, however, been prepared and it is hoped that it will appear shortly in the *Proceedings of the Institute of Radio Engineers.*

In our preliminary discussion of the Perseid observations,[1] a classification of meteor radar echoes into six basic types, A-F, was suggested. With additional observational data available it has seemed advisable to revise and expand this original classification. While the new system will be described in more detail elsewhere a brief summary is given below for convenience in future reference.

Classification of Meteor Radar Echoes

Basic type
—dependent on α (elongation from radiant)
—indicated by capital letters
A—indication of decreasing range or approach ($\alpha < 90°$)
D— " " increasing " " recession ($\alpha > 90°$)
U— " " both approach and recession ($\alpha \doteqdot 90°$)
E—two or more discrete ranges, no motion evident ($\alpha \neq 90°$)
F—one discrete range, no motion evident ($\alpha = 0° - 180°$)

Secondary characteristics
—descriptive in nature
—indicated by small letters following letter for basic type

h—instantaneous head echo moving with velocity of meteor
b—moving echo with measurable and continuously variable duration
e—two or more echoes at discrete ranges
f—one echo at a discrete range
s—duration under one second
2, 3, 4, etc.—number of components

On the above system the four echoes discussed in this note would be designated as follows:—

Geminid echo.....*Ahe3*
Lyrid echo I.....*Ahb4*
" " II.....*Uhb4*
" " III.....*Db2*

In conclusion we should like to express our thanks to all those who contributed to the success of these observational programs, in particular to Miss M. S. Burland, who was in charge of the visual observers at Ottawa, and to Messrs. Earle Webb, Bruce Bourne and Stanley Mott, who assisted at Ottawa and operated the Arnprior station.

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LA METEOROLOGIE: APERCU HISTORIQUE

Par G. Oscar Villeneuve*

Sommaire

La météorologie, faite de superstitions dans l'antiquité, n'entre réellement dans le domaine des sciences qu'avec l'invention des instruments en mesure d'évaluer mathématiquement les phénomènes atmosphériques. Ses progrès coincident avec ceux de la chimie et de la physique et c'est avec l'invention du télégraphe qu'elle permet aux chercheurs de pénétrer ses mystères.

Au Canada, elle passe du domaine théorique au domaine pratique quand on l'utilise à la prévision des tempêtes et des gelées, à la protection des forêts, aux études hydrologiques et plus tard à la prévision des conditions atmosphériques sur les routes aériennes.

Dans la province de Québec, l'utilisation locale des données météorologiques nécessite la création en 1936, d'un bureau provincial de météorologie dont les activités portent principalement sur la météorologie forestière, la climatologie, la météorologie instrumentale et les recherches.

De L'Antiquite a Nos Jours. L'homme primitif, sans secours devant les tempêtes, le tonnerre et les éclairs, attribuait ces manifestations au pouvoir des dieux, remplaçant par des superstitions les raisons que la logique ne pouvait lui donner. De ces superstitions naquirent Jupiter Pluvius, dieu de la pluie, Hélios, dieu du soleil, et Boréas, dieu du vent nord.

La civilisation s'est développée dans les régions où le climat était doux et les éléments météorologiques favorables. Quelques unes des anciennes civilisations ont été florissantes dans les vallées du Nil et de l'Euphrate où la température était belle et où l'humidité nécessaire aux cultures était apportée par les rivières et non par les nuages. Les Egyptiens étaient très dédaigneux des Grecs parce que ceux-ci avaient à compter sur le bon plaisir de leurs dieux pour obtenir la chaleur et la pluie nécessaires à leurs cultures. Les Egyptiens jouissaient alors d'une indépendance économique enviable.

Les Chaldéens et les Babyloniens ont été les premiers à progresser en astronomie et en météorologie quand ils ont essayé d'apparenter les phénomènes atmosphériques aux mouvements des corps célestes. On trouve encore des traces de leur science dans

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quelques uns des proverbes modernes sur le temps, proverbes qui attribuent différentes sortes de temps aux équinoxes et aux phases de la lune.

L'histoire de la météorologie est très différente de l'histoire de la chimie et de la physique. Le chercheur ne pouvait faire que des observations dans le sens le plus strict du mot; il ne pouvait reproduire ou même modifier dans un détail les phénomènes qu'il observait. « Ce chercheur », a dit Sir William Herschel, « semblait un homme qui entend de temps en temps quelques fragments d'une longue histoire relatée à de longs intervalles par un narrateur ennuyant et sans méthode. »

L'histoire primitive a noté le retour successif de certains phénomènes et nombre de proverbes ont pris naissance. Alors, deux sortes de météorologie nous sont parvenues: celle basée seulement sur la superstition et celle basée sur l'observation d'évenements successifs.

Le plus vieil appareil météorologique est une girouette construite par les Grecs, 100 ans avant Jésus-Christ. Cette girouette, situee à Athènes, repose sur une tour octogonale en marbre dont le sommet de chaque face porte une figure sculptée de l'un des vents.

Au cinquième siècle avant Jésus-Christ, Hippocrate, le « père de la médecine », discuta le sujet « des airs, des eaux et des pluies ». Aristote est l'auteur de « METEOROLOGICA », et dans le domaine des sciences, il a été l'autorité acceptée pendant près de deux mille ans. D'autres Grecs ont écrit sur le sujet, mais ils étaient plus intéressés dans l'assertion dogmatique que dans l'observation patiente et exacte des faits.

Après plusieurs siècles durant lesquels très peu s'est ajouté à la science météorologique, deux nouvelles influences contribuèrent au développement du sujet: la méthode inductive de Francis Bacon qui stimulait la précision des observations, et l'invention du thermomètre et du baromètre modernes. Tycho Brahe a enregistré à Prague des notes systématiques de météorologie de 1582 à 1597. Christian Europe fit usage d'une girouette et on donna plus tard à cet appareil une place proéminente au pignon des clochers d'églises. Des anémomètres à pendule pour mesurer la force du vent furent installés vers 1570 à Bologne et à Florence par l'astronome Egnatio Danti. En plus du thermomètre et du baromètre, les Italiens

développèrent aussi le pluviomètre qui a été employé pour la premiere fois par Beneditto Castelli. La plus ancienne mention de l'hygroscope se trouve dans les travaux de Nicolaus de Cusa (1401 à 1464) dans lesquels est décrite « une grande balance ayant une quantité de laine sur un côté et des pierres sur l'autre ». Cette balance était évidemment affectée chaque fois que l'air avait une inclinaison à l'humidité ou à la sécheresse. Les Italiens ont été les premiers à employer des cordes d'intestin comme hygromètres.

Les progrès de la météorologie coincident de très près avec ceux des autres sciences telles que la physique et la chimie. Au18ième siècle, Benjamin Franklin contribua à la science de la météorologie en découvrant que l'éclair et l'électricité sont identiques. Sa contribution la plus significative fut de s'aperçevoir que le temps à un certain endroit peut n'être qu'une partie d'une configuration météorologique plus grande passant au-dessus d'un pays. Otto Von Guerike, Robert Boyle et William Ferrel ont aussi apporté leur contribution au développement de la météorologie[4].

La météorologie moderne n'est cependant entrée dans le grand monde des sciences qu'après l'invention du télégraphe, qui rendit possibles les observations simultanées prises à un grand nombre de stations et recueillies ensemble à un même endroit pour étude immédiate. L'homme de science a pu se permettre alors une idée plus définie des phénomènes gigantesques de l'atmosphère. Il a été ensuite en mesure d'analyser plus complètement les données météorologiques.

Dans le passé, presque toutes les observations employées dans les prévisions atmosphériques étaient faites à la surface de la terre. Depuis quelques années, on a étudié les conditions et les mouvements de l'atmosphère à différentes élévations, et comme résultat, on en est venu à la « théorie du front polaire » sur la formation des cyclones, et à la méthode dite « de l'analyse des masses d'air » employée dans la prévision des conditions atmosphériques. Ces derniers développements en météorologie ont pour auteurs des norvégiens célèbres du nom de V. et J. Bjerknes[8].

La météorologie au Canada. La météorologie a débuté au Canada en 1839. Quelques années auparavant, les Français, les Russes, les Allemands et les Italiens avaient commencé des recherches sur les troubles magnétiques terrestres. Les Anglais, de

peur d'être devancés, décidèrent d'installer eux aussi des observatoires pour l'étude des conditions magnétiques terrestres, et en même temps l'étude des conditions atmosphériques. C'est alors qu'un militaire anglais, le lieutenant C.J.B. Riddell fut envoyé au Canada pour y installer un de ces observatoires.

Toronto fut choisie, de préférence à Montréal, comme site de l'observatoire; Montréal n'était pas propice aux observations à cause du caractère magnétique de ses roches, et Toronto était, parait-il, libre de cette influence. On construisit l'observatoire sur une propriété de l'université de Toronto, alors le King's College, et c'est le premier février 1840 qu'on commença les observations régulières. Les premiers instruments comprenaient un équipement complet pour le travail magnétique et plusieurs appareils météorologiques tels que des baromètres et des thermomètres.

Convaincre les autorités de l'importance d'un travail n'est pas une mince affaire. Les premiers directeurs de l'observatoire s'en rendirent bientôt compte. Les fonds nécessaires à sa construction étaient lents à venir et nombre d'inconvénients surgirent bientôt qui retardèrent le travail. De plus, on manquait d'espace pour le personnel et ce personnel n'était pas toujours à la hauteur de sa tâche.

Vers 1850, on réalisa toutes les difficultés et on décida que le 31 mars 1853, le gouvernement du Canada prendrait charge de l'observatoire après avoir renvoyé à Londres tous les instruments scientifiques. . . Quelques sociétés scientifiques s'objectèrent alors à la suspension des observations magnétiques et météorologiques. Elles firent des demandes au gouvernement du Canada pour que celui-ci, en prenant charge de l'observatoire, achète les instruments. Cette requête fut agréée, et le gouvernement canadien remboursa avantageusement le gouvernement anglais pour ses quelques appareils et récompensa généreusement aussi le directeur militaire d'alors pour certains livres que celui-ci laissait au bénéfice culturel de ses remplaçants.

C'est en 1855 que l'université de Toronto prit en main l'administration de l'observatoire et nomma un directeur dans la personne du professeur G. T. Kingston. A cette date, l'université devait subvenir au tiers des dépenses tandis que le gouvernement canadien s'engageait à défrayer les deux autres tiers.

Le professeur Kingston a le mérite d'avoir établi le premier réseau de stations météorologiques au Canada. Ce fut un réseau fragile, car les stations météorologiques furent établies dans les écoles régionales, et sur un total de douze postes, sept seulement furent opérés, et ils ne le furent que durant des périodes intermittentes. On donna le coup de mort à ce réseau de stations quand on cessa les subsides aux écoles en 1876. Il faut dire que le travail météorologique n'était pas considéré alors comme ayant une valeur suffisamment pratique pour qu'on se permit d'y consacrer des fonds publics.

Avec la confédération, l'observatoire de Toronto devint entièrement la propriété du gouvernement fédéral, mais il était encore administré par l'université de Toronto. On peut dire que c'est en 1871 que fut fondé le Service Météorologique du Canada. Un octroi de $5,000.00 fut mis à sa disposition par le gouvernement fédéral, et en 1874, le Service Météorologique fut placé dans les cadres administratifs du département de la marine et des pêcheries. En 1875, le Service Météorologique du Canada dépensait une somme de $35,000.00 tandis qu'aux Etats-Unis on avait dépensé $415,000.00 l'année précédente dans le même but. Disons que ce montant n'a été atteint pour la météorologie au Canada qu'en 1938.

Le premier but du Service Météorologique fut de coopérer avec le Weather Bureau des Etats-Unis pour signaler l'approche des tempêtes aux ports de l'Atlantique et des Grands Lacs. En coopération avec les compagnies de chemins de fer, le Service Météorologique renseigna aussi le public sur les prévisions atmosphériques. Ceci consistait alors à mettre en vue sur les wagons de chemin de fer certains dessins pour indiquer le beau ou le mauvais temps à venir. En 1890, on étendit le réseau des stations météorologiques jusqu'en Colombie Canadienne et dans les Territoires du Nord-Ouest. En 1894, on publia une carte mensuelle du temps, et en 1895, une carte quotidienne. C'est en 1898 que le Service Météorologique commença des observations sismologiques à Toronto et à Victoria, les deux centres de prévisions à cette époque. En 1910, on établit, à Toronto encore, une section d'aérologie, et on commença à étudier les conditions météorologiques des couches atmosphériques supérieures. On obtint des données au moyen de cerfs-volants jusqu'à une élévation de 7,900 pieds. Plus tard, on

se servit de ballons d'hydrogène pour faire des observations à des hauteurs beaucoup plus élevées dans l'atmosphère.

L'établissement d'un service de malle aérienne au Canada augmenta encore l'importance du Service Météorologique. On avait besoin, en effet, des prévisions météorologiques pour les routes aériennes. De plus, les propriétaires de vergers demandaient d'être avertis de l'approche des gelées. En protection des forêts, on avait besoin des prévisions pour combattre efficacement les feux de forêts. Les agriculteurs mettaient aussi à profit ces prévisions dans le soin de leurs cultures. Enfin, les demandes qu'on faisait au Service Météorologique du Canada furent telles qu'en 1936, une réorganisation complète s'imposait.

Les recherches sismologiques et magnétiques furent alors placées sous la direction de l'observatoire de l'Etat au département des mines et des ressources naturelles. Quant au Service Météorologique du Canada, anciennement au département de la marine et des pêcheries, il devint la division de la météorologie du service de l'air au département des transports. Ainsi, les activités de cette division sont maintenant exclusivement confinées au travail météorologique.

Il faut ajouter que les techniciens du Service Météorologique du Canada viennent tous de l'université de Toronto. En effet, l'université de Toronto, intéressée qu'elle était dans ce Service qui grandissait de jour en jour, établit en 1932 un département de météorologie décernant le diplôme de Maître ès Arts. Le personnel du Service Météorologique à Toronto y donne actuellement tous les cours de météorologie, de même que l'entrainement pratique dans cette science. C'est par ce seul moyen, à date, qu'on a recruté le personnel météorologique dont on avait besoin aux centres de prévisions et aux aéroports[2 8 9].

La météorologie dans la province de Québec. Dans la province de Québec le travail météorologique a commencé lorsque le gouvernement du Canada se mit à établir des stations dans le but de prédire les tempêtes. C'est à l'université McGill de Montréal que revient l'honneur de posséder la station météorologique la plus ancienne de la province. Cette station fut installée en 1862. Par ordre chronologique, la deuxième station fut celle de Québec. Cette dernière date de 1870. Puis viennent ensuite les stations de

Pointe au Père (1874), Cap Madeleine et Cap Chat (1883). Il est facile de constater que les endroits susmentionnés étaient sur le parcours des navires et que les postes météorologiques servaient exclusivement à la navigation.

Plus tard, à la demande du gouvernement provincial de Québec, le gouvernement fédéral installait des stations à l'intérieur des terres pour recueillir des données météorologiques et les utiliser à l'étude du régime des eaux. On étudiait, en effet, les possibilités d'utiliser la force motrice de plusieurs cours d'eau de la province. Et comme le débit des cours d'eau dépend en partie des éléments climatiques, principalement des précipitations, il était important de connaître ces éléments. C'est pour cette raison que furent établies en 1903 les stations de Brôme, Abitibi, Bic, Chicoutimi, Shawinigan et Sherbrooke. A cette nouvelle série de stations, on a ajouté par la suite celles de Ste Anne de Bellevue en 1906, de Disraéli en 1909, et de Témiscamingue en 1910.

Un fervent apôtre de la météorologie dans la province de Québec a été M. Arthur Amos, alors chef du Service Hydraulique au département des Terres et Forêts. Il a été l'un des premiers à reconnaître la valeur des données météorologiques et à les utiliser dans des travaux hydrologiques. Il s'est personnellement occupé de fournir aux observateurs en météorologie « une brochure en langue française traitant de la manière de faire les observations ».

De toutes les stations faisant rapport au Service Météorologique du Canada en 1916, quatorze étaient subventionnées par le département provincial des Terres et Forêts. En 1917, ce nombre était porté à dix-sept.

Il n'y avait alors aucune compilation spéciale des données météorologiques pour la province de Québec. De plus, le manque d'inspection et de surveillance des stations de la part du gouvernement fédéral, fit que nombre de données n'avaient aucune valeur. Pour remédier à cet état de choses, le Service Hydraulique, le Service des Statistiques et la Commission des eaux Courantes décidèrent en 1919 de publier en collaboration un bulletin météorologique distinct pour la province de Québec. On s'entendit avec le Service Météorologique du Canada pour que les rapports soient d'abord soumis à un organisme provincial avant d'être expédiés à Toronto.

En 1927, le réseau météorologique provincial comprend 76 stations dont 31 sont subventionnées par le département des Terres et Forêts. Le Service Météorologique du Canada fournit les appareils qui consistent dans un abri thermométrique, des thermomètres à maxima et à minima et un pluviomètre. La Commission des Eaux Courantes reçoit les rapports et les expédie à Toronto après transcription des données. Le Service des Statistiques publie un bulletin mensuel qu'il envoie à tous ceux qui en font la demande.

Pour simplifier l'administration des stations météorologiques, le Service Hydraulique du département des Terres et Forêts en donne tout le contrôle à la Commission des Eaux Courantes en 1928.

Cependant, il y avait un autre service au département des Terres et Forêts qui s'occupait d'observations météorologiques: c'était le Service de la Protection. Dès 1911, le surintendant de la protection des forêts était convaincu qu'il fallait tenir compte des précipitations atmosphériques dans la protection efficace des forêts, et à cette fin, reçevait plusieurs rapports du réseau météorologique provincial. Toutefois, ce n'est qu'en 1928 que le Service de la Protection établissait à son propre compte onze stations de météorologie forestière pour compléter les données qu'il reçevait déjà des autres stations. A cette date, le Service Météorologique du Canada envoyait au Service de la Protection et aux associations de protection des forêts, des prévisions atmosphériques pour les régions où les dangers d'incendies forestiers étaient élevés. Cependant, comme les prévisions provenant de Toronto n'étaient pas assez précises et qu'elles n'avaient par conséquent aucune valeur pratique, les associations de protection réclamèrent en 1930 à la suite de la Quebec Forest Industries Association, l'établissement à Québec d'un bureau de prévisions météorologiques.

En 1932, le chef du Service de la Protection, M. Henri Kieffer, soucieux d'utiliser toutes les possibilités techniques à la prévention des feux de forêts, nomma un inspecteur à charge d'installer et de faire fonctionner au maximum les stations de météorologie forestière. Cet inspecteur, M. Isaie Nantais, fit appliquer par les observateurs le système d'indice d'inflammabilité développé par W. H. Beall et J. G. Wright du Service Forestier Fédéral[7].

Trois ans plus tard, le Service de la Protection établit à Duchesnay, comté de Portneuf, P.Q., une station de recherches pour étudier spécialement l'indice d'inflammabilité des peuplements forestiers. La méthode de W. H. Beall et J. G. Wright ne s'appliquait qu'aux peuplements de pin blanc et de pin rouge. Il s'agissait alors d'en trouver une qui soit applicable à tous les massifs boisés.

Le directeur de la station expérimentale de météorologie, tout en poursuivant des recherches à Duchesnay, organisa le réseau des stations météorologiques du Service de la Protection pour en obtenir des données comparatives. Malgré leur excellente localisation et leur bon rendement, les stations ne pouvaient être opérées d'une manière pratique sans une méthode uniforme de travail et une centralisation des rapports. On manquait d'instructions précises, de formules propres aux observations météorologiques et même d'instruments en mesure de s'accomoder aux conditions climatiques du pays. D'un autre côté, l'inspection systématique des stations météorologiques devenait un besoin pressant à mesure que le réseau prenait de l'importance. Il fallait de plus déterminer une zone d'action à chaque station et élaborer un plan d'ensemble permettant d'établir de nouvelles unités dans toutes les parties boisées de la province. Enfin, il fallait instituer un organisme devant vérifier les observations et leur interprétation dans la détermination de l'indice d'inflammabilité des forêts. C'est alors qu'on fonda en 1936, au sein du Service de la Protection, un Bureau de Météorologie adapté aux besoins de la protection des forêts. La province de Québec possède donc depuis cette date, son propre organisme technique en météorologie[10].

(*La suite prochainement*)

THE ORBITS AND DIMENSIONS OF THE COMPONENTS OF THE SPECTROSCOPIC BINARY H.D. 43246.*

By R. M. Petrie

ABSTRACT

THE orbital elements and dimensions are calculated from radial velocities determined from thirty-five single-prism spectrograms. The spectrum is shown to be composite, the presence of the fainter star being indicated by the *K*-line of Ca II and the strength of the hydrogen lines. The period of revolution is 23.1756 days and the orbit is nearly circular. An anomalous feature of the system is that the fainter star is the more massive, the ratio being 2.2. Spectrophotometric measures give the spectra as F5 and B8, and a magnitude difference of 1.5 mag., the F star being the brighter. The F star is found to be a normal main-sequence object while the B star is under-luminous and highly compressed.

Introduction

The star H.D. 43246, $\alpha(1900) = 6^h10.1^m$, $\delta(1900) = +28^\circ\ 54'$, $m_v = 7.3$ was announced as a spectroscopic binary in 1938 by Christie and Wilson,[1] a range of 110 km./sec. being found from five spectrograms. The writer, in 1939, undertook to observe the system for radial velocities and to calculate the orbital elements. From 1939 until 1942 a total of thirty-four single-prism spectrograms was obtained. No difficulty was encountered in finding a preliminary value of the period of revolution and the determination of the orbital elements proceeded in an uneventful manner. However, certain peculiarities were noted during the measurement of the plates. The spectrum was classified in the *Henry Draper Catalogue* as A2p but while the hydrogen lines are strong, many absorption lines due to the neutral metals are present, those of Fe I, Cr I, and Ca I being particularly noticeable. In addition, the appearance of the region of the *K*-line of Ca II is striking. One would expect, from the development of the metallic spectra, a broad, strong, absorption at *K* but the line is narrow and relatively weak. Furthermore, the metallic lines in that region, chiefly those of iron, are not easy to see. These facts suggested that the

*Contributions from the Dominion Astrophysical Observatory No. 9.

[1] *Mount Wilson Contr.* No. 593; *Ap. J.*, vol. 88, p. 34, 1938.

spectrum was composite; in fact a marked similarity was noted to that of the composite binary H.D. 144208-9 which had been investigated recently by the writer[2] and which had an interesting and peculiar fainter component. The spectrograms were, therefore, re-examined and the *K*-line was measured on all the plates which were well exposed in that region. The radial velocities from this line showed unmistakably that they arose in a secondary spectrum, being opposite in phase to the curve derived for the primary. This discovery made it desirable that a detailed study of the system be undertaken in order that the orbits and dimensions be found, since such data are very scarce for the composite systems described as "spectrum binaries."[3] This paper gives the results of the investigation of the orbits of the two components, spectrophotometric studies giving the brightness and spectrum of each star, and finally their probable dimensions, masses and densities.

The Radial Velocities and Orbital Elements

Radial velocities are available from thirty single-prism spectrograms obtained at Victoria and the five Mount Wilson observations already mentioned. Of the Victoria plates, sixteen gave a linear dispersion at Hγ of 30 A./mm. (IM), while the remainder gave a lower dispersion, 51 A./mm.(IS). On the average, twelve lines were measured on a plate and the wave-lengths used were those adopted at Victoria for the A-F stars.[4] The lines are chiefly due to neutral iron and all except *K* referred to the brighter component only, as an investigation of the individual line residuals showed. The individual plate velocities are listed in Table I which gives the Julian date of each observation, its phase from J.D 242.9926.119, the observed velocity, number of lines measured, dispersion used, and the assigned weight as well as the velocities given by the *K*-line of Ca II.

The period of revolution was found without difficulty. An accurate value was made possible by the early observations at Mount Wilson, the radial velocities being kindly communicated to the writer by the discoverers. The value of the period employed

[2] *J.R.A.S.C.*, vol. 37, p. 277, 1943, and *Publ. Dom. Ap. O.*, vol. 7, p. 273, 1942.
[3] Hynek, *Contr. Perkins O.*, No. 10, 1938.
[4] *P. Dom. Ap. O.*, vol. 6, p. 297, 1936.

in assembling the observations was 23.176 days and a final improved value, viz., 23.1756 days, was derived after the solution for the elements.

Since it was unnecessary to include the period, the observations were grouped into thirteen normal places for a least-squares

TABLE I—VICTORIA RADIAL VELOCITIES OF H.D. 43246

	Julian Date 2,400,000 +	Phase days	Primary Star				*K*-Line Velocity km./sec.
			Velocity km./sec.	n.	p.	Inst.	
1	20707.755	13.392	+60.9	15	0.5	IM	
2	9710.731	16.368	+60.6	15	0.5	"	− 5.8
3	9902.031	22.263	−36.0	17	0.7	"	+19.8
4	05.019	2.076	−65.6	14	0.5	"	+15.0
5	27.942	1.823	−68.2	14	0.5	"	+22.6
6	30.020	3.901	−61.6	12	0.2	IS	+14.4
7	46.010	19.891	+ 9.6	12	0.3	IM	
8	55.080	5.785	−45.2	13	0.5	"	+26.1
9	55.955	6.660	−36.8	9	0.1	IS	+31.2
10	72.959	0.489	−50.2	16	0.5	IM	
11	73.865	1.395	−63.9	13	0.4	IM	
12	76.739	4.269	−68.0	14	0.2	IS	+50.1
13	76.946	4.476	−61.8	12	0.2	"	+41.0
14	77.853	5.383	−45.6	14	0.2	"	+35.4
15	29978.783	6.313	−35.7	12	0.3	IM	
16	30005.758	10.112	+26.8	12	0.3	"	
17	40.799	21.978	−14.7	9	0.2	IS	+ 4.7
18	58.760	16.763	+72.8	7	0.2	IM	
19	60.769	18.772	+28.4	15	0.5	"	− 3.6
20	78.763	13.590	+72.3	12	0.3	"	
21	81.690	16.517	+46.2	10	0.3	"	
22	101.690	13.342	+66.9	12	0.4	"	
23	353.957	10.677	+24.3	12	0.2	IS	
24	354.799	11.519	+46.7	12	0.2	"	−15.0
25	402.849	13.218	+58.1	11	0.2	"	
26	430.753	17.946	+37.0	9	0.1	"	
27	434.728	21.919	−36.8	11	0.2	"	+ 8.0
28	444.745	8.763	− 3.8	14	0.2	"	
29	451.720	15.738	+45.8	4	0.1	"	
30	30453.706	17.724	+41.3	12	0.2	"	−41.6

solution for orbital elements. As a preliminary plot showed that the eccentricity is small it was possible to employ the rapid and convenient solution devised by Sterne.[5] Preliminary circular elements were adopted as shown in Table II which also lists the final corrected values together with their probable errors. It appears from this that a real, although small, eccentricity is present and so the elliptic elements are adopted.

TABLE II—THE ORBITAL ELEMENTS OF H.D. 43246

	Preliminary	Final	
P	23.176 days	23.1756 days	± 0.0006
T		J.D. 2429926.119	± 1.713
ω		133.6	± 26.6
e	0.0 (assumed)	0.024	± .011
K_1	68.0 km./sec.	67.2	± 0.73 km./sec.
K_2		31.3	± 3.3 km./sec.
V_0	0.0 km./sec.	+0.5	± 0.54 km./sec.
$a_1 \sin i$		21,400,000 kms.	
$a_2 \sin i$		10,000,000 kms.	
$m_1 \sin^3 i$		0.73 ⊙	
$m_2 \sin^3 i$		1.57 ⊙	
m_2/m_1		2.2	± 0.23

In determining the orbital elements (except for K_2, the semi-amplitude of the secondary) velocities of the primary star only were used since they are so much more accurate than those for the secondary which depend upon the measures of a single, not very well-defined, feature. The radial velocities from the K-line may be used, however, to determine the amplitude of the velocity curve of the secondary star. Radial velocities for the secondary were available from six IM plates and nine IS plates (as given in Table I) and for each of these the equation of condition:

$$K_2 = -K_1\left(\frac{V_2 - V_0}{V_1 - V_0}\right)$$

allows us to compute a value of K_2; V_1 and V_2 are the observed velocities of primary and secondary, respectively. The value of

[5] *Proc. National Acad. Science*, Wash., vol. 27, p. 175, 1941.

K_2 was found to be 31.3± 3.3 km./sec., while the probable error of a single measure of the K-line was found to be ±9 km./sec. The probable error for an average plate for the primary is ±3.8 km./sec.

The final elements are represented by the radial-velocity curves drawn in figure 1 where individual velocities are plotted. Probably the most interesting result of the orbital study is the mass-ratio, m_2/m_1, which shows that the star represented by the K-

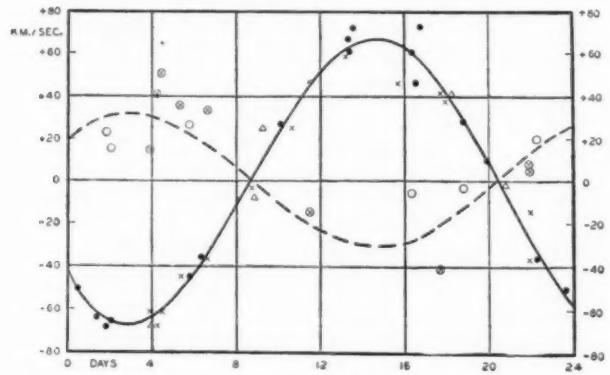

FIG. 1. *The Radial-velocity Curves of H.D. 43246.*

The curves representing the final elements are shown, the zero phase at J.D. 2429926.119. Individual plate velocities are plotted, IM plates are represented by dots, IS plates by crosses, while the Mount Wilson velocities are shown as triangles. The dotted velocity curve is that of the secondary star, IM plates being shown as circles and IS plates as circles containing a cross.

line of Ca II is the more massive although it is, presumably, the fainter. This is a very unusual circumstance as it is an almost universal rule that the brighter component of a double star is the more massive; any other arrangement, of course, is a violation of the mass-luminosity relation. Nevertheless, this result appears to be well established. In spite of the considerable scatter about the secondary curve the computed mass-ratio is $m_2/m_1 = 2.2 \pm 0.2$. The error of over one hundred per cent. required to reverse the

above conclusion can scarcely be admitted and so we have strong evidence that one or other component of this system is a peculiar star.

Spectrophotometric Measures and Results

The measures and calculations presented in this section follow closely those described for the binary H.D. 144208-9[6] and the reader is referred to that article for further details. The spectrum is studied in order to derive the spectral types of the components and their absolute magnitudes. This is done by first classifying the primary star in the usual way from line-intensity ratios and then determining the relative brightness of the secondary from certain effects which it produces upon the primary spectrum. Line profiles and total absorptions were measured for Hζ, *K*, Hδ, Hγ and Hβ, and line-depths were measured for some twenty-five metallic lines chiefly due to neutral iron.

The spectrum of the primary was classified by comparing line-depth ratios in H.D. 43246 with those in the spectra of *Procyon*, ι *Piscium*, and the sun, all spectra being obtained with the same instrument. The resulting type for H.D. 43246 was F2. It is known that the presence of the secondary star, if not allowed for, causes one to classify the F star too "early." This is because the secondary weakens the metallic lines and Hγ is strengthened, and the classification depends largely upon the strengths of several metallic lines compared with that of Hγ. After making allowances for this effect it was apparent that the primary was close to F5, the class finally adopted. We may compare this with the Mount Wilson type where, not aware of the composite character, it was classed as F0.[7]

The absolute magnitude was next estimated by comparison with α *Persei* and ι *Piscium*, employing the sensitive pairs of lines listed by Adams, Joy, Humason and Brayton[7], and also by Harper and Young.[8] The writer's estimate of the absolute magnitude made in this way was + 1.5. Since this was essentially in agreement with the Mount Wilson value of + 2.1, and since the latter is part of a large body of homogeneous estimates by experienced

[6] *J.R.A.S.C.*, vol. 37, p. 277, 1943.
[7] *Mount Wilson Contr.*, No. 511, 1935.
[8] *P. Dom. Ap. O.*, vol. 3, p. 3, 1924.

observers, it was decided to adopt it. The important question here is whether the primary star is a giant or a main sequence object and of that there appears to be little doubt. The adopted values for the primary star are, then, spectrum F5, $M_v = +2.1$.

We turn now to the spectrum and luminosity of the fainter star whose presence is revealed by;

(*a*) the anomalous *K*-line,

(*b*) the strengthening of the hydrogen lines over those in a normal F5 spectrum, and

(*c*) the weakening of the metallic absorption lines, this effect becoming increasingly evident at shorter wave-lengths. From these effects information is obtained about the secondary spectrum.

The profile of the composite *K*-line as derived from measures of three spectrograms (relative radial velocity being eliminated before the average was taken)is shown in figure 2. The profile, at first sight rather peculiar, is readily interpreted in terms of the combination of a normal solar-type line and the *K* region of an early-type spectrum. The wide and deep absorption in the F-type spectrum is largely filled in by the spectrum of the secondary and provides a "special window" through which the continuous spectrum and weak Ca II absorption of the fainter star may be observed. It is this modification of the *K*-line, together with the enhancement of the hydrogen lines, which leads one to classify composite spectra of the kind encountered here among the A stars.

The equivalent width of the narrow central absorption is found to be 0.6 angstroms, which approximates the average value for B8 stars. There is considerable scatter about this mean value for stars in general but we may say from this that the spectrum of the secondary is probably B8 or B9. It can scarcely be as early as B5 nor as late as A2 and still produce the combined feature shown in figure 2.

The total absorption of the *K*-line was measured as 4.1A., the mean from four plates. Apart from its indication of the spectral type of the secondary star, no further use was made of the composite *K*-line. The reason is the presence, in the primary spectrum, of an abnormally strong line of Sr II at λ4078 which, according to a recent investigation by Weaver,[9] indicates that the *K*-line is weaker

[9] *P.A.S.P.*, vol. 58, p. 246, 1946.

than average for the spectral type. We cannot then adopt a "standard" intensity for the line in the primary spectrum to calculate the light-ratio as described below for the hydrogen lines and it seemed safer not to use the *K*-line in any of the following calculations. Such calculations were, in fact, made and gave the result that the early-type star was nearly twice as bright (at *K*) as the F star. This obviously erroneous conclusion is exactly what one would expect if the *K*-line in the F-type component is weaker than usual for its spectral type and confirms, for this star, the results described more generally by Weaver.

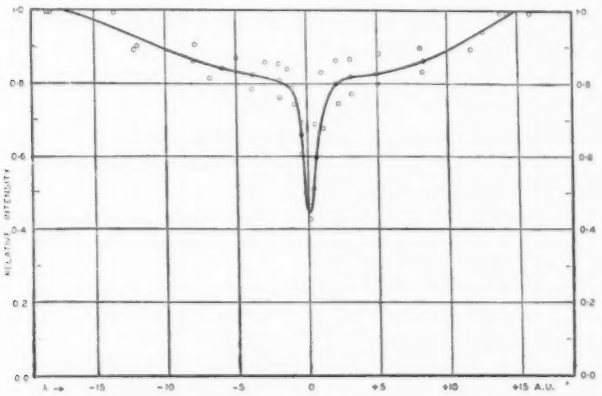

FIG. 2. *The Composite K-line in the Spectrum of H.D. 43246.*

The line profile is shown as determined from intensity measures on three IM plates. The broad shallow wings are all that remains of the wide deep absorption line in the F spectrum. The central part is almost entirely produced in the secondary star, its continuous spectrum and relatively weak absorption line being observed because the primary spectrum in the K region is absorbed in the atmosphere of the F star.

The total absorptions of the hydrogen lines, measured on microphotometer tracings, are listed in Table III along with those in the spectrum of ι *Piscium*, a main sequence star of type F4. Table III exhibits two instructive features. First the hydrogen lines are much stronger, nearly twice, in the composite spectrum

TABLE III—EQUIVALENT WIDTHS OF HYDROGEN LINES

	H.D. 43246	ι *Piscium*
Hζ	6.4 A.	3.3 A.
Hδ	6.9 A.	3.7 A.
Hγ	5.7 A.	3.0 A.
Hβ	4.6 A.	3.7 A.

and, secondly, there is a marked increase in Balmer line intensity from Hβ to Hζ not evident in ι *Piscium* nor in other normal spectra in which the hydrogen lines have been measured. Both of these effects point strongly to the presence of an "early-type" secondary spectrum in the observed features.

We now proceed to calculate the light ratio, l, (secondary to primary) from the hydrogen lines. Let

A = observed absorption of the composite line;

A_b = line absorption in a normal F5 spectrum, taken to be that in ι *Piscium*;

A_f = line absorption in the secondary spectrum taken to be the values ordinarily found for B8-A0 stars.

Then we may write[6]

$$l = \frac{A - A_b}{A_f - A}$$

where l is the desired ratio of luminosity at the wave-length of the line considered. In the computation it was assumed that the hydrogen lines in the secondary were as intense as those, on the average, in an A0 star. This is considered justifiable even if the secondary were as early as B8 since there is reason to believe it to be sub-luminous and therefore it exhibits stronger than average hydrogen lines. Actually, the values of l are little affected by the exact value chosen for A_f between those for B8 and A0. The computed values of l are listed in Table IV.

Values of l may be determined from the observed depths of the metallic lines upon the assumption that they are modified by pure continuous spectrum of the primary. Here we may write

$$l = \frac{a_e}{a_0} - 1$$

TABLE IV—VALUES OF l IN H.D.43246

λ	Lines	l
3889	Hζ	.71
4028	6	.68
4101	Hδ	.58
4174	5	.46
4242	7	.44
4340	Hγ	.42
4347	5	.46
4861	Hβ	.14
4905	2	−0.02

where a_0 is the observed depth of the absorption line in the composition and a_c is the assumed central depth of the line in a normal F5 spectrum taken to be that measured for ι *Piscium*. A number of the stronger lines, some twenty-five in all, were measured in H.D. 43246 and, by comparison with ι *Piscium*, values of l were computed. The spectral region covered was from λ3957 to λ4919 and the majority of the lines chosen were due to neutral iron. Mean values of l grouped into five sets are given in Table IV where the mean wave-length and number of lines in each mean are tabulated.

THE TEMPERATURE AND MAGNITUDE OF THE FAINTER STAR

The values of l, as derived in the previous section, are plotted against wave-length in figure 3. It is gratifying to find that the values derived by the two methods, *i.e.*, from the intensities of the hydrogen lines and from the depths of the metallic lines, agree quite well when one considers the number of assumptions which had to be introduced and the accidental errors in deriving line intensities and line-depths from single-prism spectrograms.

The plotted points in figure 3 should define a curve, the slope of which gives the temperature of the secondary star (in terms of that of the primary), while the ordinate gives the light-ratio or magnitude difference at any desired wave-length. The observations, however, indicate an unacceptably high temperature—one well over 30,000°—and it is not considered that a reliable temperature can be obtained from them. The assumptions used in deriving l, the effect of errors

of observation, and above all the insensitivity of the spectrophotometric gradient to varying temperature above 10,000°, all conspire to render invalid, it is believed, the temperature derived from these values of l. In view of this result it would be interesting to obtain slitless spectra of H.D. 43246 along with those of some standard objects and to measure the gradient in the composition directly.

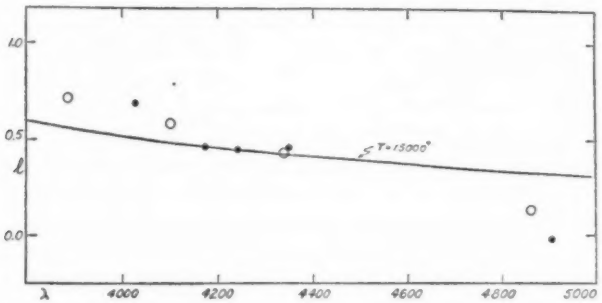

FIG. 3. *The Values of l Calculated from the Hydrogen and Metallic Lines.*

The values of the light-ratio calculated from the central depths of the metallic lines are shown as dots, those from the total absorptions of the hydrogen lines by circles. The curve is for a temperature of the secondary star of 15,000°K, adjusted to pass through the most reliable determinations of l between λ4200 and λ4400.

Under the circumstances it is considered better to adopt a temperature, since we have some evidence on this point from the study of the *K*-line, which indicated a spectral type about B8. A curve of pre-determined shape may be then fitted to the observed values of l and the visual magnitude difference may be derived. Consequently, a temperature of 15,000° was adopted for the secondary star and adjusted to the points as shown in figure 3. From this curve we find l at λ5350 and derive

$$\Delta m_v = 1.5$$

It may be remarked here that the adoption of a higher temperature (steeper slope) for the curve through the points in figure 3 leads to

a larger value of Δm. For example, a curve corresponding to 30,000° gives $\Delta m = 1.9$ and this would strengthen our conclusions regarding the peculiar nature of the fainter star.

The System of H.D. 43246

Collecting the results derived in the previous sections we have the dimensions shown in Table V, first four entries.

Table V—The System of H.D. 43246

	Primary	Secondary
Spectral Type	F5	B8
Absolute Magnitude	+2.1	+3.6
Temperature	6,500°	15,000°
Mass $\times \sin^3 i$	0.73⊙	1.57⊙
Mass	2.0⊙	4.3⊙
Radius	3.0⊙	0.46⊙
Mean Density	0.08⊙	40⊙

If we assume now that the primary is a normal star obeying the mass-luminosity relation we may calculate the orbital inclination from the absolute magnitude, spectral type and derived value of $m\sin^3 i$. The inclination is found to be 45°. This allows us to calculate the mass of the secondary star. The radii may be obtained from the temperatures and absolute magnitudes and the mean densities follow. The numerical values are given in the second part of Table V. A parallel calculation was made for an assumed temperature of 10,000° corresponding to a spectral type of A0. This leads to an absolute magnitude of about + 3.2, a radius 0.75 ⊙, and a mean density approximately 10 ⊙.

To summarize, the general conclusions reached in this study of the binary star H.D. 43246 are that the brighter component, of spectrum F5, is a main sequence star normal in magnitude, mass, and density, and that the fainter component is a sub-luminous peculiar star. Its spectral type is late B, or perhaps A0, and the mass is about average for its spectrum, but it is much fainter than its mass and type require—by as much as four magnitudes. It is consequently highly compressed with a diameter a fraction of the normal value and a mean density about one-thousandfold that of a

normal late B-type star. It thus belongs to the group of under-luminous stars situated between the main stellar sequence and the white dwarfs and often referred to as "sub-dwarfs."

In conclusion it is interesting to speculate upon the possible frequency of occurrence of such under-luminous stars. In two binary systems investigated here recently by the writer, the secondary has been found to be a sub-dwarf. They were selected at random insofar as this characteristic is concerned which leads one to suspect that binary systems with one component a sub-dwarf may be quite numerous. It would be worth-while to examine more closely any main seqüence star of solar type whose *K*-line is weak or anomalous in appearance. The existence of binaries with sub-luminous components may, in many cases, be revealed only in this way.

The Dominion Astrophysical Observatory,
Victoria, B.C.
November 1946.

OUT OF OLD BOOKS

By Helen Sawyer Hogg

Wales's Journal of a Voyage in 1768

In this Journal, November 1947, we reprinted portions of the astronomical observations of the transit of Venus in 1769, made by Wales and Dymond at Prince of Wales Fort, now Churchill, on Hudson's Bay. I am indebted to Dr. Vilhjalmur Stefansson and Dr. J. Tuzo Wilson for information as to further records of this expedition; and especially indebted to Dr. Wilson for the loan of rare material from his personal Arctic library.

The journal of the experiences of William Wales was published in the *Philosophical Transactions of the Royal Society*, vol. LX, 1770, a year later than the report of the transit. Possibly the recent formation of the Arctic Institute has stimulated literature on early Arctic exploration. At any rate, the current issue of the *Queen's Quarterly* (Kingston, Ontario), vol. IV, no. 1, 1948, carries an article by Richard Glover on William Wales, entitled "An Early Visitor to Hudson Bay." We quote Glover's description of Wales:

> Dymond seems to have been nobody in particular, but Wales had a distinguished career. His visit to Churchill was his first big adventure. He followed it by sailing round the world as astronomer to Captain Cook on his second and third voyages and finally taught mathematics in Christ's Hospital. During his mastership three of the most brilliant of all Christ's Hospital boys passed through the school—Coleridge, Lamb, and Leigh Hunt. As 'Grecians' they were not in Wales's mathematical class, but his personality impressed at least two of them. Hunt remembered him as "a good man of plain, simple manners, with a large person and a benign countenance"; and Lamb, though awed by the rigour of his discipline, adds: "There was in William Wales a perpetual fund of humour, a constant glee about him, which, heightened by an inveterate provincialism of North-country dialect, absolutely took away the sting from his severities."

In "Hearne's Journey from Hudson's Bay to the Northern Ocean", (Champlain Society, 1911), J. B. Tyrrell says of Wales,

> His presence for more than a year among the little band of white men assembled at this remote fur-trading post on Hudson Bay must have had a helpful

influence in preparing Hearne for his great explorations overland to the Arctic Ocean.

In order to observe the transit in June from Churchill, Wales and Dymond were forced to spend thirteen months in the region, remaining through the winter of 1768 in order to be on hand for the transit which would occur before the shipping season opened in 1769. According to Dr. J. Tuzo Wilson, this voyage of Wales and Dymond was the only trip specifically for astronomical purposes in early days in Arctic Canada. Because of its importance from the standpoint of historical astronomy, and the great rarity of the original volume, we will reprint in this issue and that of July-August more than half of Wales's "Journal of a Voyage," in order that our readers may enjoy first-hand the quaint and vivid phraseology in which Wales describes the conditions that he found.

His "Journal" is written in a scientific manner, with personalities ignored, and almost no comments on the discomforts he must have endured, especially during the winter, when the ice on the planks of his bed was half as thick as the planks themselves! Actually his strongest remarks are applied to the "moschetto" and other flying insects. I have included all references of an astronomical or meteorological interest in this account. And I have departed from my usual custom of printing only astronomical subject matter to include such things as Wales's account of the Eskimaux woman "with a child in each boot top"; and the quaint remark that on the 22d and 23d of August "the people were allowed to write to their friends in England".

By modern standards the departure of the ship from England was leisurely indeed, as nearly a month elapsed after the ship sailed from Gravesend on the Thames before it finally left Hoy-head in the Orkneys. Wales makes little comment on the rigours of the voyage, but one cannot help wondering what the feelings of the sailors were when the ship entered the ice pack, and to avoid hitting the ice floes "they turned the ship several times in a minute; the wind blowing a strong gale all the time."

Our present planetary symbols are used to indicate the day of the week throughout this account.

Received January 25, 1770

XIII. JOURNAL OF A VOYAGE, MADE BY ORDER OF THE ROYAL SOCIETY, TO Churchill River, ON THE NORTH-WEST COAST OF Hudson's Bay; OF THIRTEEN MONTHS RESIDENCE IN THAT COUNTRY; AND OF THE VOYAGE BACK TO England; IN THE YEARS 1768 AND 1769: BY William Wales.

Read March 8 and 15, 1770.

It must be observed, that the Astronomical, and not the Nautical Day, is every where to be understood in the following Journal.

1768.

☉ May 29th. HAVING settled all my affairs in London; about 22 hours I set off for Greenwich, where I received my instructions from the Rev. Mr. Maskelyne, his Majesty's Royal Astronomer.

☽ the 30th. About 2 hours went on board a Gravesend boat; got to that place about 7, and went directly on board the ship. A. M. delivered my instructions to Mr. Dymond, for him to copy, according to Mr. Maskelyne's directions.

♂ the 31st. About 2 hours weighed, and the wind being contrary, we tided it all the way from that place to Yarmouth road; where we arrived and came to an anchor, about 20 h. on ♄, June the 4th.

We lay in Yarmouth Road until the 7th, when we unmoored, and came to an anchor in Cairstown harbour on ☉, the 12th, about 14 hours; having had strong gales, and thick weather, with drizzling rain almost all the time.

We lay in this place, and in the road, till ♃, the 23d, taking in ballast and live stock; having for the most part nasty thick, and cold fogs: About 16 hours the commodore made the signal to un-moor, and about 18 h. we got under way, and stood through Hoy-sound. At 20 h. Hoy-head bore S.E. by compass, dist. about 4 miles. At noon I observed the sun's meridian altitude to be 54° 10′¼, whence the true lat. of the ship was 59° 3′ ¾; the course by compass since 20 h. was W.N.W. at the rate of 4⅘ miles per hour. Hence the lat. of Hoy-head is 59° 2′ N. and if we account its long. west of Greenwich 3° 20′. the long. of the ship at this time was 4° 5′ W.

. . .

☿ June 29th. . . . At 13ʰ 5′ the eclipse of the moon was considerably begun; I estimated it about 3 digits. At 14ʰ 11′ I judged the beginning of total darkness happened; but clouds rendered it a little uncertain. . . .

♂ July 5th. Being by account in long. 45° ¼ W. and by observation in Lat. 57° 43′ N. I made the following observations for determining the long. of the ship. . . .

I did not make use of the telescope when I made these observations, as its field is too small to use when the ship has much motion, which was the case at this time.

We were certain that we were now well a-breast of cape Farewell; having the two preceding days passed several pieces of driftwood. . . .

♄ the 16th. The former part of these 24 hours we ran through several very strong replings of the tide, which made us suspect that we might be nearer the entrance of the Straights than our accounts shewed us to be; and therefore about 11 h. the whole fleet brought to, as the fog was exceeding thick. . . .

About 16 h. we saw the first isle of ice; but it was at too great a distance for me to give any farther account of it.

☽ July the 18th. This day, and yesterday, we have run through several very strong riplings of tide; and have passed by many islands of ice: but their distance, and the thickness of the fog, rendered it impossible for me to give any account of them.

♂ the 19th. Passed within a cable's length of a very large island of ice, or rather frozen snow, for it appeared to me to be nothing else. It was about as high out of the water as our main-top, and was adorned both on its top and sides with spires; and indented in the most romantic manner that can be imagined.

. . .

♄ July the 23rd. About ½ past 2, we made the island of Resolution, which forms the north shore, at the entrance of Hudson's Straits, bearing from us N.W. b. W. It lies, by my account, in lat. 60° 29′ ½ N. and long. 65° 9′ W.

☉ the 24th. . . . About 10 there came along side of us a boat, with several Eskimaux women, and two or three boys; but no men. They traded with the people some of their cloaths, and a few toys of their own making; such as models of their bows, harpoons, &c. but I saw nothing else that they had to trade; nor had they any weapons, either of offence or defence, along with them. The boat is so well described and delineated in Crantz's history of Greenland, that it is entirely needless to attempt it here. . . .

☽ July the 25th. This afternoon I told 32 islands of ice as I stood on the quarter-deck. This number is about double of what I have ever seen before, at one time.

1st. . . . This day, as I was observing the sun's meridional altitude, there came along side of us three Eskimaux in their canoes, or, as they term them, Kiacks, but who had very little to trade, except toys. None of these had along with them any weapon that I saw, except a kind of dart, evidently constructed for sea purposes, as it had a buoy fixed to it, made of a large bladder blown up.

The men have on their legs a pair of boots, made of seal skin, and soled with that of a sea horse; these come barely up to their knees; and above these they have breeches made of seal, or deer skin, much in the form of our seamens short trousers. The remaining part of their cloathing is all in one piece, much in the form of an English shift; only it comes but just below the waist-band of their breeches, and has a hood to it, like that of a woman's cloak, which serves instead of a cap. Over these they have a kind of foul-weather jacket, made of the same leather with the legs of their boots, which they fasten very tightly about their necks and wrists; and when they are in their Kiacks (which also are extremely well described by Mr. Crantz) are likewise fastened in such a manner round the circular hole which admits the man's body, that not the least drop of water can get into it, either from rain or the spray of the sea.

The dress of the women differs not from that of the men, excepting that they have long tails to their waistcoats behind, which reach quite down to their heels; and their boots come up quite to their hips, which are there very wide, and made to stand off from their hips with a strong bow of whalebone, for the convenience of putting their children in. I saw one woman with a child in each boot top.

. . .

☿ July 27. This evening I told 58 islands of ice, all going directly across the Straits from the mouth of the above-mentioned inlet, [the North-Bay] at the rate of several miles per hour. . . .

♀ July 29th. At 15 h. we hauled the wind to the southward, the ice being quite thick a-head of us. At 19 h. hauled the wind to the N.W. and stood through the ledge of ice, as, for aught that appeared to the contrary, it might reach quite to Cape Walsingham, which now bore S.W. It consisted of large pieces close jambed together: in the place where we attempted to pass through, it was not quite so close. It is really very curious to see a ship working amongst ice. Every man on board has his place assigned him; and the captain takes his in the most convenient one for seeing when the ship approaches very near the piece of ice which is directly a-head of her, which he has no sooner announced, but the ship is moving in a quite contrary direction to what it was before, whereby it avoids striking the piece of ice, or at least, striking of it with that force which it would otherwise have done. In this manner they turned the ship several times in a minute; the wind blowing a strong gale all the time. . . .

♄ July 30th. This evening I staid upon deck till after midnight, in hopes to have observed the ☽'s distance from a star; but, after trying for near an hour, I was obliged to give it up, on account of the twilights, which are amazingly bright in these high latitudes. There is another great inconvenience which attends observations of this kind here, viz. a red haziness round the horizon, to a considerable height, rendering the stars very dim; but at the same time large, something like the nucleus of a comet. I have been disappointed by one or other of these, two or three times before; but this is the more vexatious, as we are now amongst many islands, headlands, &c. whose longitudes are entirely unknown, and on which account an observation would have been singularly useful. . . .

☉ August 7th. About 5 saw the low land of Cape Churchill, bearing from the S. to S.W. b. S. but the haziness of the horizon made the land put on a different appearance every 4′ or 5′. I cannot help taking notice of one circumstance, as it appears to me a very remarkable one. Though we saw the land extreamly plain from off the quarter deck, and, as it were, lifted up in the haze, in the same manner as the ice had always done; yet the man at the mast head declared he could see nothing of it. This appeared so extraordinary to me, that I went to the main-top-mast-head myself to be satisfied of the truth thereof; and though I could see it very plain both before I went up, and after I came down, yet could I see nothing like the appearance of land when I was there. I had often admired the singular appearance of the ice in these parts, which I have seen lifted up 2° or 3° at a distance of 8 or 10 miles, although when we have come to it, we have found it scarcely higher than the surface of the water.

At 21 h. we fired a gun, and thought we heard one in answer to it; which, if true, must have been from the factory.

☽ August 8th. We saw the flag-staff of the factory, with the colours on it, bearing S.W. by W. but lost it again in the haze a few minutes afterwards. At 3 we saw the factory-land, and the flag-staff very plain, S.W. b. W. At 4 made the appointed signal, which was properly answered; after which, we bore away directly for the mouth of the river, and at 5 anchored, there being little wind, and the ebb tide was running out very strong. At this time Cape Merry bore S.W. and Eskimaux Point N.W. b. W. from whence, and the run of the ship since noon, I infer that the latit. of the factory is 58° 59′ N. and by Mr. Dymond's observation in 95° 33′ W. or, according to mine, 95° 2′ W.

A little before noon we weighed, and worked up the river to the usual place where the ship lies, where, about two the 9th, she was safe moored.

☿ the tenth, we went on shore, for the first time. We were met on the beach by Captain Richards, who went with us up to the factory, and introduced us, in form, to the governor, Mr. Moses Norton, who, as well as Mr. Fowler, the person who succeeded him, behaved to us with great civility, and kindness. After breakfast, the surgeon of the factory was so kind as to walk with us several miles, to shew us the country. . . .

I found here three very troublesome insects. The first is the moschetto, too common in all parts of America, and too well known, to need describing here. The second is a very small flie, called (I suppose on account of its smallness) the sand-flie. These in a hot calm day are intolerably troublesome: there are continually millions of them about one's face and eyes, so that it is impossible either to speak, breathe, or look, without having one's mouth, nose, or eyes full of them. One comfortable circumstance is, that the least breath of wind disperses them in an instant. The third insect is much like the large flesh-flie in England; but, at least three times as large: these, from what part ever they fix their teeth, are sure to carry a piece away with them, an instance of which I have frequently seen and experienced.

August 11th, 12th, 13th, 15th, 16th, 17th, and 18th, we got on shore the observatory and instruments; but the people were all so busy unloading the ship, and repairing the quay, craft, &c. that we could not begin to put any part of the observatory up.

♂ the 16th, I went with Mr. Fowler about ten miles up the country, which, as far as we went, was nothing but banks of loose gravel, bare rocks, or marshes, which are over-flowed by the spring tides, and do not get dry before they return, and overflow them again. Our errand was, to see if we could not find some land likely to produce corn; and in all that extent we did not find one acre, which, in my opinion, was likely to do it. In some of the marshes the grass is very long, and with much labour they cut and dry as much hay as keeps three horses, two cows, a bull, and two or three goats, the whole winter. . . .

August the 19th and 20th. We laid the foundation of the observatory in its proper place and position, which was on the S.E. bastion, the higher and lower observatories nearly N.N.E. and S.S.W. of each other respectively. This place

and position, though inconvenient in some respects, were, in my opinion, the most eligible for our purpose. We also got up the sides thereof, and fixed up a stiff plank of dry English oak to screw the clock to; this plank was about 5½ feet out of the ground, 4 feet in it, 16 inches broad, and 4½ thick, and supported with spurs to make it steady. There was likewise placed at the foot of it, in the most solid manner possible, a stone of about a quarter of a ton weight, with a flat surface, to set the bottom of the clock-case on; so that the clock stood entirely independent of the observatory.

The 22d and 23d, the people were allowed to write to their friends in England, so I employed myself to the same purpose.

The 24th, 25th, 26th, and 27th. The carpenters were employed in making us bed-places, &c. having hitherto had no where to lie but on the floor.

The 29th, 30th, and 31st, were employed on the observatory; we got on the circular parts and roof of each. On the 31st the ship sailed for England.

September 1st, 2d, 3d, 5th, 6th, and 7th. We were employed in finishing the observatory. On the 8th we set up the two clocks. This morning the snow was about two inches deep on the plains. The 9th, put up the stove in the observatory, the two thermometers, and repaired such parts as had been broken in the carriage. ♄ the 10th, we filled the barometer, and put it up; we also took out the quadrant, which we found much tarnished, especially the arc, and adjusted it ready for observation.

☽ Sept. 12th. I found that the roof of the observatory would not permit us to take zenith distances of any stars on the arch of excess of the quadrant, without moving it farther to the southward; and as I could not hit on any method of determining the error of the line of collimation, which to me appeared satisfactory, except by observations of stars near the zenith, I resolved to take up the floor of the observatory, and remove the piles on which the quadrant stood farther south; and which, with the assistance of the house carpenter, I effected on the 16th, so as answer our purpose completely.

From this time to August the 28th, 1769, I kept no journal, except of the weather; the original of which has been given in to the Royal Society; and which is, in reality, the only thing we have to keep a journal of here in the winter season; and therefore, what I have farther to offer is in short memorandums, which I made when the circumstances mentioned occurred to me; but as they will scarcely appear intelligible, in that form, to any but myself, I shall endeavour to throw it into a sort of historical account of the seasons, and manner of living, in that part of the world.

(*To be continued*)

REVIEWS OF PUBLICATIONS

Chambers's Mineralogical Dictionary. Pages 47, plates 40; 5½ × 8 in. Chemical Publishing Co. Inc., Brooklyn, New York; 1948. Price $4.75.

The layman will be pleased to find this mineralogical dictionary with its fourteen hundred odd terms interpreted in clear yet simple language. With little or no difficulty he is able quickly to "run down" not only the common ore and gangue minerals but also numerous rocks.

The minerals are listed with their chemical composition, common crystal forms (if such exist), physical and chemical properties, and frequently with their uses. Since mineral association is oftentimes a help in identification and interpretation in the field, the reader will find this book invaluable for its lists of associated minerals. The members of the zeolite, feldspar, pyroxene, and other families of rock-forming minerals are listed in detail together with their slowly varying chemical and physical properties. For the ore minerals the more important localities are given. The numerous igneous, sedimentary, and metamorphic rocks are listed with their geologic horizons.

This dictionary contains some two hundred coloured reproductions of minerals in massive and idealized crystal form. We feel obliged to point out, however, that the colours of a few of these illustrations are not altogether accurate. The author should certainly be complimented upon his definitions, which the student will find very useful.

D. K. Norris

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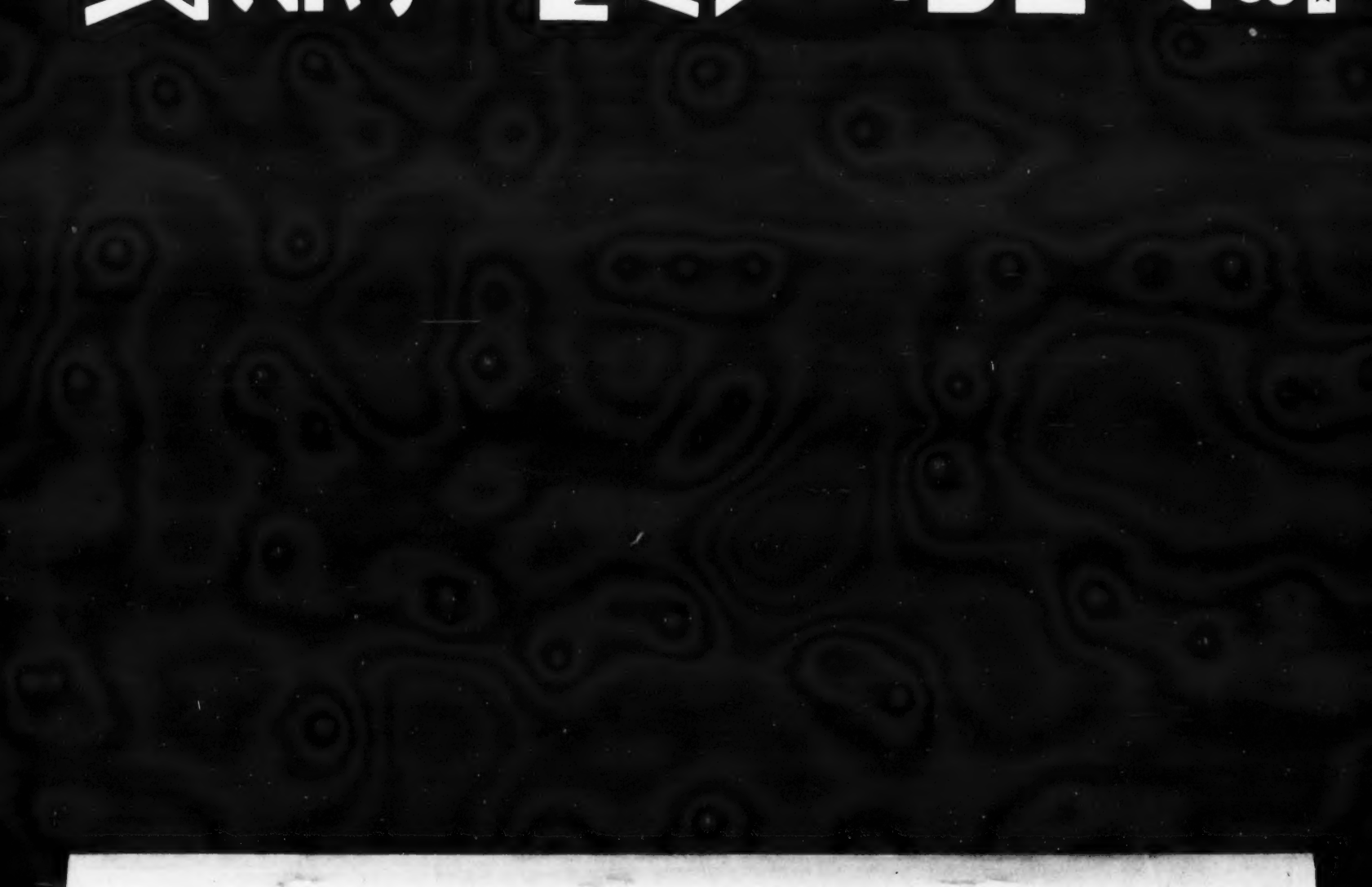
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